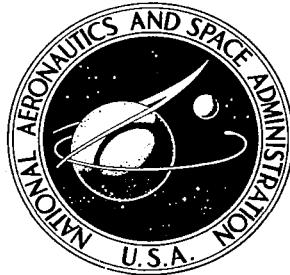


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DETERMINATION OF WELDABILITY AND
ELEVATED TEMPERATURE STABILITY
OF REFRACTORY METAL ALLOYS
II - Long-Time Temperature Stability
of Refractory Metal Alloys

by G. G. Lessmann and R. E. Gold

Prepared by

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for Lewis Research Center

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16. Abstract The thermal stability of refractory metal alloys which showed promise for application in high temperature space power systems was determined. Electron beam and gas tungsten arc welds were evaluated as well as base metal. Only the very fabricable columbium and tantalum base alloys were evaluated. These included T-111, T-222, Ta-10W, FS-85, D-43, B-66, C-129Y, Cb-752, and SCb-291. These represent all of the commercial alloys prominent at the inception of the aging studies. The purpose of this study was to screen the fabricable alloys for high temperature stability over long exposure times. Bend testing for ductility changes as reflected in the bend transition temperature was emphasized as a screening technique. Tensile testing, hardness determinations, and extensive optical and electron metallurgy were also employed. Fracture modes of the alloys were also studied. Some aging effects were noted in all of the alloys studied. None of these effects would be detrimental in normal application of these materials. These effects ranged from simple grain growth in the case of Ta-10W and SCb-291 to classic overaging response in the D-43 alloy.			
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FOREWORD

This evaluation was conducted by the Westinghouse Astronuclear Laboratory under NASA contract NAS 3-2540. Mr. P. E. Moorhead, of the Lewis Research Center Space Power Systems Division, was the NASA Project Manager for the program. Mr. G. G. Lessmann was responsible for performance of the program at the Westinghouse Astronuclear Laboratory.

The objectives delineated and results reported herein represent the requirements of Task III of contract NAS 3-2540. Additional comprehensive investigations which were conducted as a part of this program are the subjects of additional reports. The final reports for this contract are the following:

- I - Weldability of Refractory Metal Alloys (CR-1607)
- II - Long-Time Elevated Temperature Stability of Refractory Metal Alloys (CR-1608)
- III - Effect of Contamination Level on Weldability of Refractory Metal Alloys (CR-1609)
- IV - Post Weld Annealing Studies of T-111 (CR-1610)
- V - Weldability of Tungsten Base Alloys (CR-1611)

Additional salient features of this program have been summarized in the following reports:

G. G. Lessmann, "The Comparative Weldability of Refractory Metal Alloys," The Welding Journal Research Supplement, Vol. 45 (12), December, 1966.

G. G. Lessmann and R. E. Gold, "The Weldability of Tungsten Base Alloys," The Welding Journal Research Supplement.

D. R. Stoner and G. G. Lessmann, "Measurement and Control of Weld Chamber Atmospheres," The Welding Journal Research Supplement, Vol. 30 (8), August, 1965.

G. G. Lessmann and D. R. Stoner, "Welding Refractory Metal Alloys for Space Power System Applications," Presented at the 9th National SAMPE Symposium on Joining of Materials for Aerospace Systems, November, 1965.

D. R. Stoner and G. G. Lessmann, "Operation of 10^{-10} Torr Vacuum Heat Treating Furnaces in Routine Processing," Transactions of the 1965 Vacuum Metallurgy Conference of the American Vacuum Society, L. M. Bianchi, Editor.

G. G. Lessmann and R. E. Gold, "Thermal Stability of Refractory Metal Alloys", NASA Symposium on Recent Advances in Refractory Metals for Space Power Systems, June, 1969.

D. R. Stoner, "Welding Behavior of Oxygen Contaminated Refractory Metal Alloys," Presented at Annual AWS Meeting, April, 1967.

TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
I.	INTRODUCTION	1
II.	TECHNICAL PROGRAM	2
	ALLOYS	2
	AGING PARAMETERS	3
	SPECIMEN PREPARATION	5
III.	RESULTS AND DISCUSSION	9
	HIGH STRENGTH ALLOYS OF GREATEST INTEREST	9
	T-111 (Ta-8W-2Hf)	16
	T-222 (Ta-9.6W-2.4Hf-0.01C)	29
	FS-85 (Cb-27Ta-10W-1Zr)	31
	OTHER SOLID SOLUTION + DISPERSION STRENGTHENED ALLOYS	33
	B-66 (Cb-5Mo-5V-1Zr)	33
	D-43 (Cb-10W-1Zr-0.1C)	34
	Cb-752 (Cb-10W-2.5Zr)	40
	C-129Y (Cb-10W-10Hf-0.1Y)	42
	SOLID SOLUTION ALLOYS	43
	Ta-10W	43
	SCb-291 (Cb-10W-10Ta)	43
IV.	CONCLUSIONS	45
V.	REFERENCES	47
	APPENDIX A (PROGRAM DATA COMPILATION)	48
	APPENDIX B (TENSILE DATA TABULATION FOR ALL ALLOYS)	152

LIST OF ILLUSTRATIONS

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1	Typical Tensile Test Schedule for Aged Specimens	4
2	Ultra High Vacuum Annealing Furnaces	8
3	Ultimate Tensile Strength of T-111 as a Function of Aging Parameters	10
4	Ultimate Tensile Strength of T-222 as a Function of Aging Parameters	11
5	Ultimate Tensile Strength of FS-85 as a Function of Aging Parameters	12
6	Bend Ductile-Brittle Transition Temperature of T-111 as a Function of Aging Parameters	13
7	Bend Ductile-Brittle Transition Temperature of T-222 as a Function of Aging Parameters	14
8	Bend Ductile-Brittle Transition Temperature of FS-85 as a Function of Aging Parameters	15
9	Effect of Post Weld Annealing on Aging in T-111 Welds	17
10	T-111 Longitudinal Weld Tensile Ductility at 32° F After Aging as Indicated	18
11	Typical Microstructures of Weld, HAZ and Base Metal of T-111 GTA Weld Specimens as a Function of Post Weld Thermal History	19
12	Microstructures of T-111 After Indicated Post Age Anneals	21
13	Electron Micrograph and Electron Diffraction Single Crystal Point Pattern of Particle Extracted from T-111 Fracture Surface	24
14	Schematic Representation of Response of T-111 Weld Structure to Aging	27
15	Typical Microstructures of Selected T-222 GTA Weld Specimens as a Function of Post Weld Thermal History	30
16	Typical Microstructures of FS-85 GTA Weld Specimens as a Function of Post Weld Thermal History	32

LIST OF ILLUSTRATIONS (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
17	Bend Ductile-Brittle Transition Temperature of B-66 as a Function of Aging Parameters	35
18	Ultimate Tensile Strength of D-43 as a Function of Aging Parameters	36
19	Microstructures of D-43 GTA Weld Specimens as a Function of Post Weld Thermal History	38
20	D-43 Base Metal Aged 10,000 Hours at 2400° F	39
21	Ultimate Tensile Strength of Cb-752 as a Function of Aging Parameters	41

LIST OF TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
1	Alloys Evaluated for Thermal Stability	2
2	Optimized Weld Conditions for 0.035 Inch Sheet	6
3	In-Process Interstitial Analyses	7
4	Results of Electron Microprobe Study of Microsegregation in T-111 GTA Welds	25

I. INTRODUCTION

This report summarizes results of thermal stability studies sponsored by the National Aeronautics and Space Administration, Space Power Systems Division. In this program the structural effects of long-time exposures at elevated temperatures were determined for promising refractory metal alloys. Refractory metal alloys are uniquely suited for many space power hardware applications because of their excellent high temperature strength and compatibility with liquid alkali metal working fluids. However, they have not been extensively utilized because of their relatively high cost. Hence, this program provided the needed detailed definition of the performance of these alloys following long-time elevated temperature exposures.

The alloys evaluated were primarily those considered to be fabricable by welding. Hence, weld stability as well as base metal stability was emphasized. The thermal stability study was preceded by a weldability study in which the base line parameters were established for use throughout the thermal stability study. This assured a consistent basis for processing and comparing the stability of the various alloys.

The alloys were screened for thermal stability by exposures between 1500 and 2400° F and hold times up to 10,000 hours. Sputter ion pumped furnaces were used exclusively providing an optimum furnace environment of less than 10^{-8} torr total pressure. This assured that specimens would remain uncontaminated even after 10,000 hour exposures. Further, the potential load loss in event of furnace failure was nil since ion pumped systems are totally closed and do not lose vacuum with loss of power.

Bend testing (to determine the ductile-brittle transition temperature) was used extensively for screening since it provides an excellent indication of a wide variety of structural interactions. Over 3000 bend tests were required. Bend test screening was complemented by tensile testing to 2400° F for each alloy requiring over 600 tensile tests. Final analyses

of instabilities were supported with optical and electron microscopy as required.

II. TECHNICAL PROGRAM

ALLOYS

The alloys evaluated in this program are listed in Table 1 which shows their nominal composition and general metallurgical classification. Specific processing parameters, as-received structure and chemistry has been documented elsewhere⁽¹⁾. All these materials were procured in the recrystallized condition and to optimum processing schedules where these were identified by suppliers. Hence, in so far as possible, all alloys were normalized for long life testing.

TABLE 1 - Alloys Evaluated for Thermal Stability

Alloy	Classification**	Nominal Composition (Wt.%)
T-111	Highest Creep Strengths Gettered Alloys*	Ta-8W-2Hf
T-222		Ta-9.6W-2.4Hf-0.01C
FS-85		Cb-27Ta-10W-1Zr
Ta-10W	Solid Solution Strengthened Ungettered Alloys*	Ta-10W
SCb-291		Cb-10W-10Ta
B-66	Solid Solution + Dispersion Strengthened Gettered Alloys*	Cb-5Mo-5V-1Zr
D-43		Cb-10W-1Zr-0.1C
C-129Y		Cb-10W-10Hf+Y
Cb-752		Cb-10W-2.5Zr

* Reactive Element Addition, Zr or Hf, Provides Corrosion Resistance in Liquid Alkali Metals

** For Weldability Ratings See Reference 1.

Of the alloys evaluated, T-111, T-222 and FS-85 eventually received the greatest emphasis in this program. This resulted because they were identified in the earlier welding phase of this program and in companion creep and corrosion test evaluations as those alloys demonstrating optimum combinations of these characteristics. Hence, they demonstrated the greatest potential for advanced space power system applications.

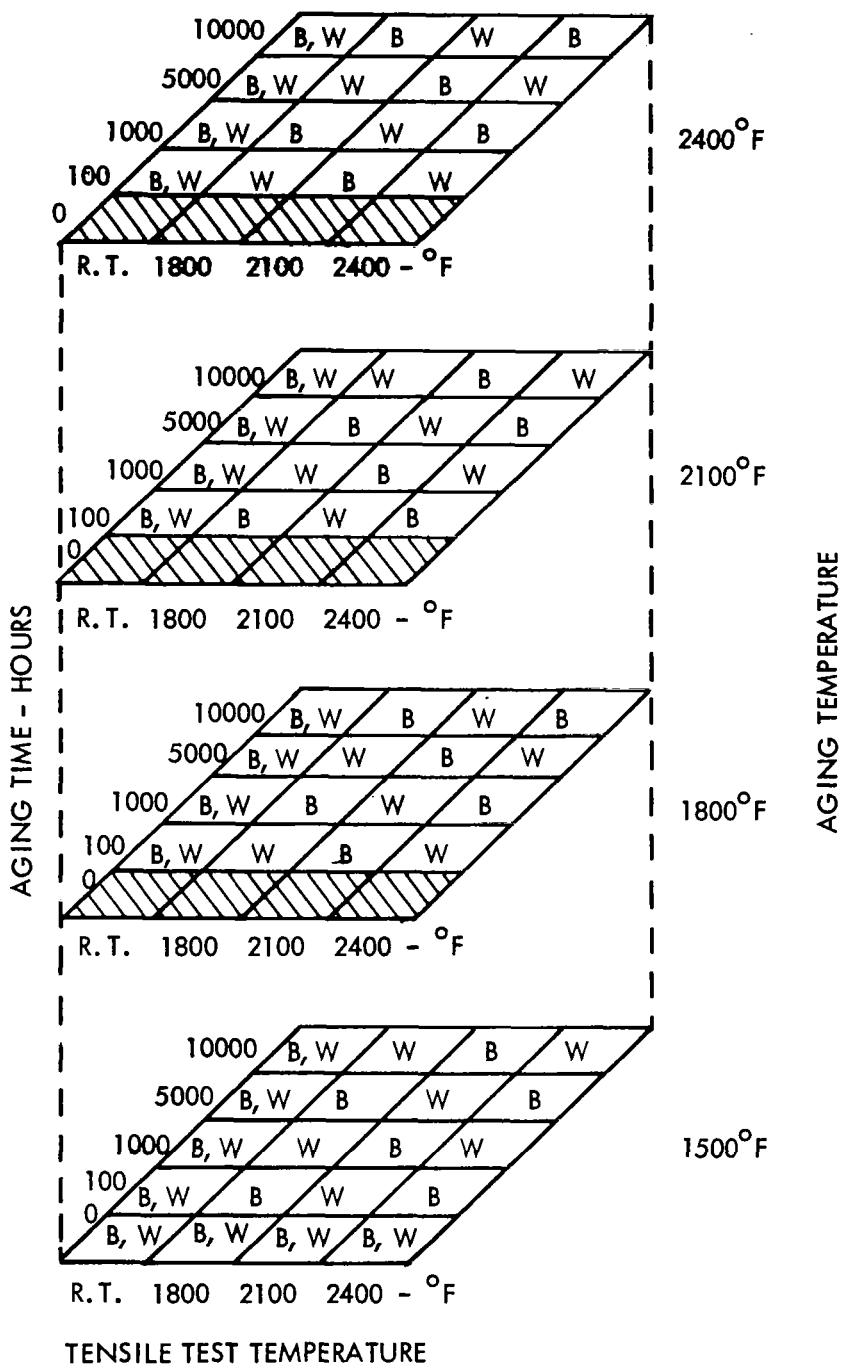
AGING PARAMETERS

The aging matrix for this program was as follows:

<u>Aging Times, Hrs.</u>	<u>Aging Temperatures, °F</u>
100	1500
1,000	1800
5,000	2100
10,000	2400

All alloys were tested at all temperatures through 1000 hours of aging. The most promising alloys were carried through completely to 10,000 hours. T-111, T-222 and FS-85 were aged at all combinations, D-43 and B-66 received modest attention beyond 1000 hours and all the other alloys were evaluated only through 1000 hours.

For each temperature-time combination each alloy was evaluated by determining bend transition temperatures of base metal, tungsten arc welds and electron beam welds all in both the longitudinal and transverse directions. In addition room and elevated temperature tests were conducted in accordance with the test matrix shown in Figure 1. Optical and electron metallography, hardness traverses and chemistry determinations were performed as required



B = BASE METAL SPECIMEN
 W = WELD METAL SPECIMEN, TRANSVERSE
 // = DUPLICATE CONDITION,
 NOT RETESTED

FIGURE 1 - Typical Tensile Test Schedule for Aged Specimens

to analyze results and demonstrate adequacy of experimental techniques.

SPECIMEN PREPARATION

Specimens were prepared for aging by pickling, welding, post weld annealing, blanking and machining and repickling in sequence. Following final pickling specimens were handled only with clean cotton gloves prior to aging. Specimen groups were packaged by alloy and wrapped in tantalum foil for aging. All alloys were then aged together for any particular time-temperature combination. Welding parameters and post weld anneals were selected to provide maximum ductility as previously established⁽¹⁾. These are listed in Table 2. Since all alloys were normalized to optimum starting ductility, we rationalized that they would be most sensitive to structural instability. Selection of a post weld anneal further satisfied a general requirement for corrosion resistance in refractory metal alloys. All specimens were produced from 0.035 inch sheet. Again, general details of specimen preparation, dimensions and test procedures have been previously documented^(1,2). Maintenance of optimum cleanliness was emphasized in every phase of processing.

Aging was accomplished in Varian ultra-high vacuum sputter-ion pumped furnaces. These provided pressures from 10^{-11} torr to 10^{-8} torr for aging. Numerous checks for contamination of specimens were performed and all proved negative as shown typically by the analyses tabulated in Table 3. These furnaces have been fully characterized for this application⁽³⁾. The high vacuum facility is shown in Figure 2.

TABLE 2 - Optimized Weld Conditions for 0.035 Inch Sheet

Alloy (1)	Process	Parameters (2)	One Hour Post Weld Anneal Temp., °F (3)	Weld Width Top/Bottom (inches)	BDBTT, °F ⁽⁴⁾	
					Long. Bends	Trans. Bends
Ta-10W	GTA	7.5-1/4-118	None	.190/.180	<-320	<-320
	EB	15-1/2-4.5	None	.049/.034	<-320	<-320
T-111	GTA	15-3/8-115	2400°F	.195/.189	<-320	<-320
	EB	15-1/2-3.8	2400°F	.038/.027	<-320	<-320
T-222	GTA	30-1/4-190	2400°F	.180/.159	<-320	<-320
	EB	15-1/2-3.8	2400°F	.039/.026	<-320	<-320
B-66	GTA	15-3/8-86	None	.190/.180	0	+75
	EB	25-3/16-3.2	1900°F	.036/.024	-225	-175
C-129Y	GTA	30-3/8-110	2400°F	.180/.130	-200	-225
	EB	50-1/2-4.1	2200°F	.040/.026	-250	-250
Cb-752	GTA	30-3/8-87	2200°F	.129/.090	-75	0
	EB	15-3/16-3.3	2400°F	.036/.017	-200	-200
D-43	GTA	30-3/8-114	2400°F	.159/.143	+100	0(5)
	EB	50-1/2-4.4	2400°F	.040/.027	-225	-225
FS-85	GTA	15-3/8-90	2400°F	.204/.195	-175	-175
	EB	50-3/16-4.4	2200°F	.038/.026	-200	-200
SCb-291	GTA	15-1/4-83	2200°F	.160/.150	-275	-275
	EB	50-1/2-4.4	None	.038/.027	<-320	-250

- As-received alloys were in the R_x condition prior to evaluation, i. e. , structurally optimum for high temperature stability and strength.
- For GTA Welds: Speed (ipm) - Clamp Spacing (in.) - Amperes
 For EB Welds: Speed (ipm) - Clamp Spacing (in.) - Milliamperes (All EB welds with 60~, 0.050 inch longitudinal deflection and 150 KV beam voltage)
- The post weld anneal was selected for optimum ductility but is also assumed to achieve an averaged structure with respect to internal reactive metal-oxygen reactions thus enhancing compatibility with alkali metals.
- BDBTT ≈ Bend Ductile Brittle Transition Temperature at 1t Bend Radius Except FS-85 Welds at 2t Bend Radius.
- Probable Value (Determined Value <-125°F).

TABLE 3 - In-Process Interstitial Analyses (Wt. ppm)

Alloy	Element	Base Metal As-Received	As-Welded GTA Welds	500 Hour Age (a)				10,000 Hour Age (a)		
				1800°F	2400°F	1500°F	1800°F	2100°F	2400°F	
T-111	C	48	34	36	44	30	80	53	45	
	O	15	24	20	13	12	13	13	20	
	N	18	26	24	24	24	27	23	21	
T-222	C	100	125	79	150	150	150	140	140	
	O	29	22	45	32	25	15	46	30	
	N	10	16	66	8	9	8	8	7	
FS-85	C	12	14	39	---	48	47	48	38	
	O	98	73	75	---	51	96	70	75	
	N	50	41	24	---	45	47	41	27	

(a) Aged specimens in nearly all cases were base metal.

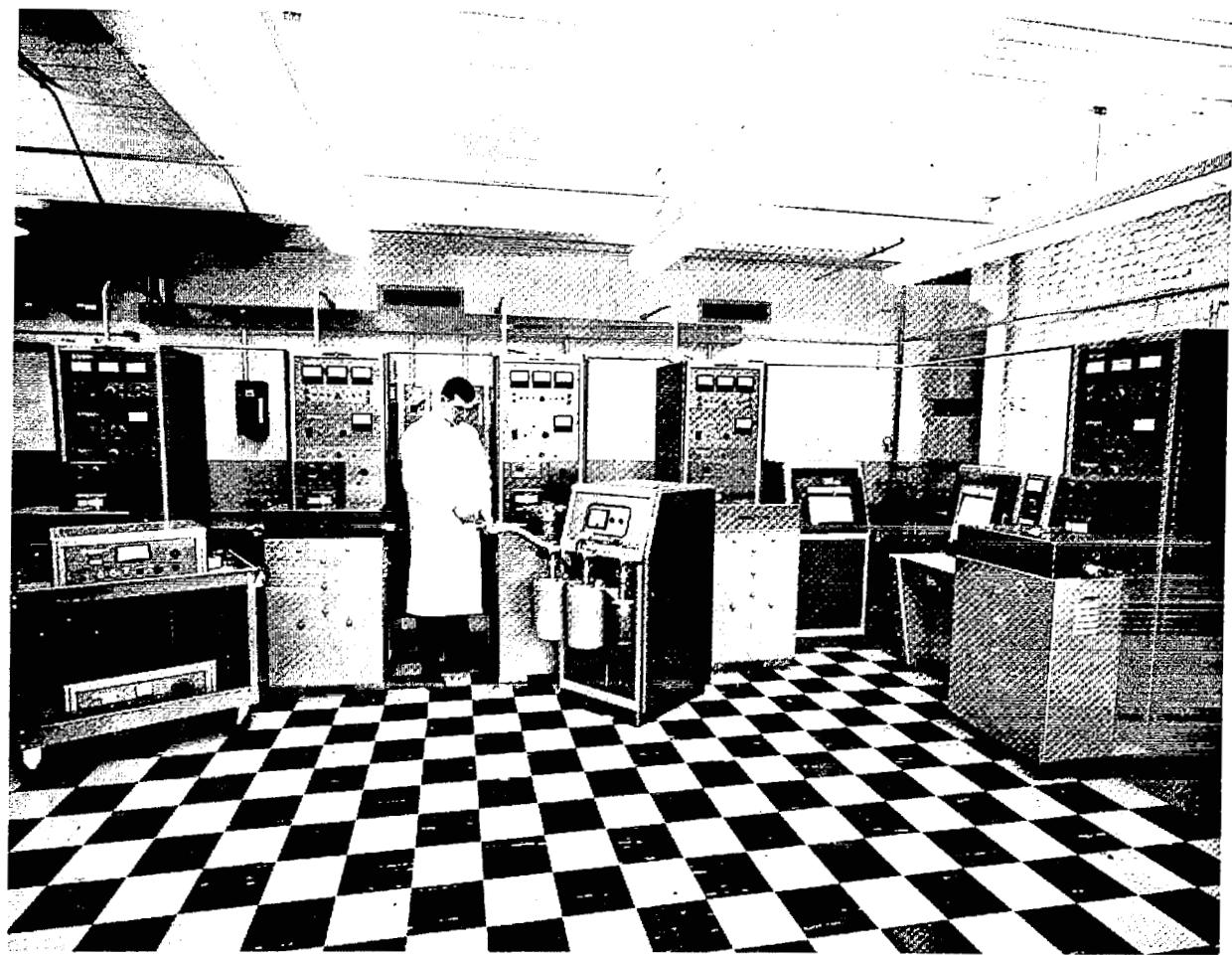


FIGURE 2 - Ultra High Vacuum Annealing Furnaces

III. RESULTS AND DISCUSSION

(In the following presentation and discussion of results, only those Figures and Tables required for continuity of the discussion are provided. The complete compilation of data accumulated pursuant to this program is provided in the Appendices.)

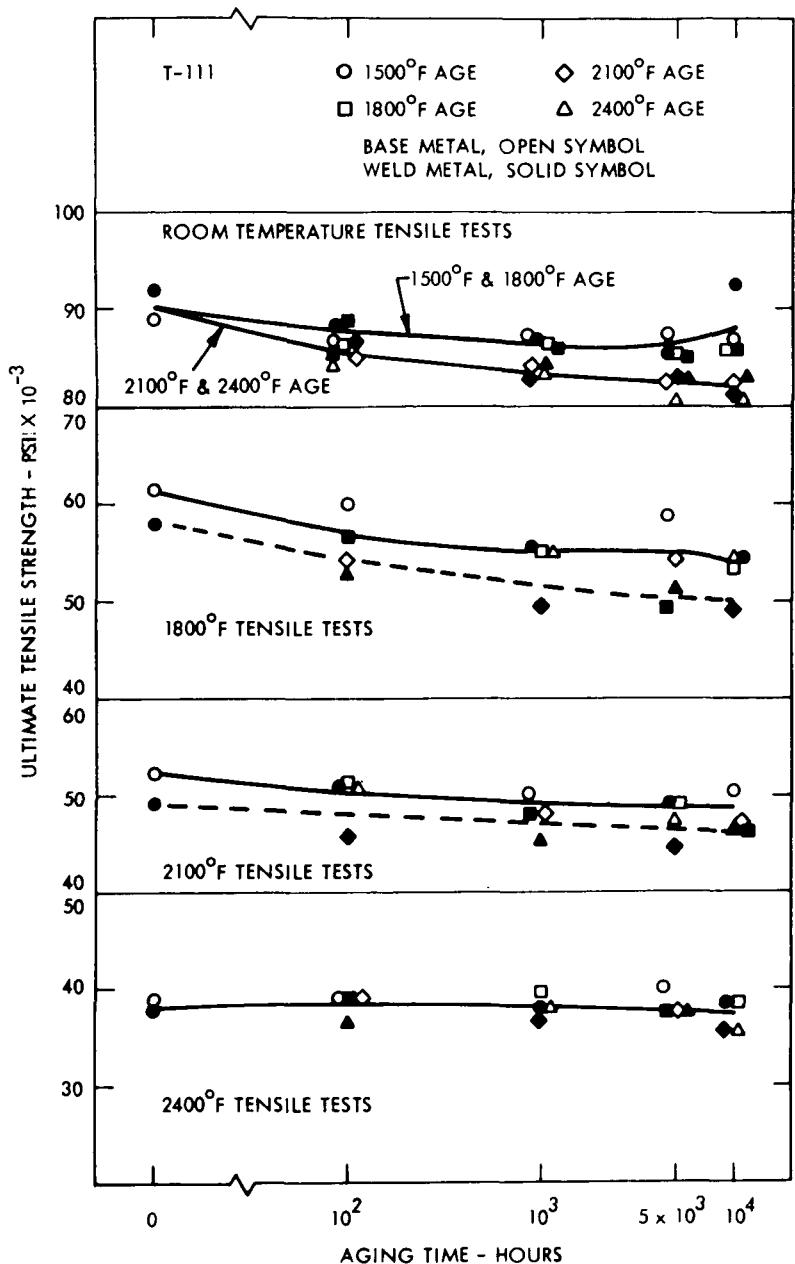
HIGH STRENGTH ALLOYS OF GREATEST INTEREST (T-111, T-222, FS-85)

These alloys are grouped for discussion both because of their similarity in thermal stability results and because they all provide an excellent balance of creep strength, weldability and liquid alkali metal corrosion resistance. The behavior of FS-85 differed from that of T-111 and T-222 only in respect to fracture mode. Typical with most other columbium alloys, FS-85 displayed a classic abrupt transition from ductile-to-brittle behavior in bend testing. In contrast T-111 and T-222 bend specimens responded to aging by displaying an increased temperature for ductile tearing primarily in the weld metal. This was based on the 1t bend test for the tantalum alloys which is essentially a go-no go test for 33-1/3% outer fiber strain.

The behavior of T-111, T-222, and FS-85 following long time exposures at elevated temperatures was markedly similar. The ultimate tensile strength at room temperature, 1800, 2100 and 2400°F as a function of aging time is shown in Figures 3, 4 and 5 for T-111, T-222 and FS-85, respectively. The tensile strength of FS-85 shows no change within the range of conditions evaluated while a modest decrease in the tensile strength of T-111 and T-222 is seen to result from the aging. The decrease is most significant for tests at 1800°F. This could be rationalized on the basis of strain aging which is pronounced at this temperature for both T-111 and T-222. Aging at 1500°F had much less effect on the 1800°F tensile strength than aging at the higher temperatures.

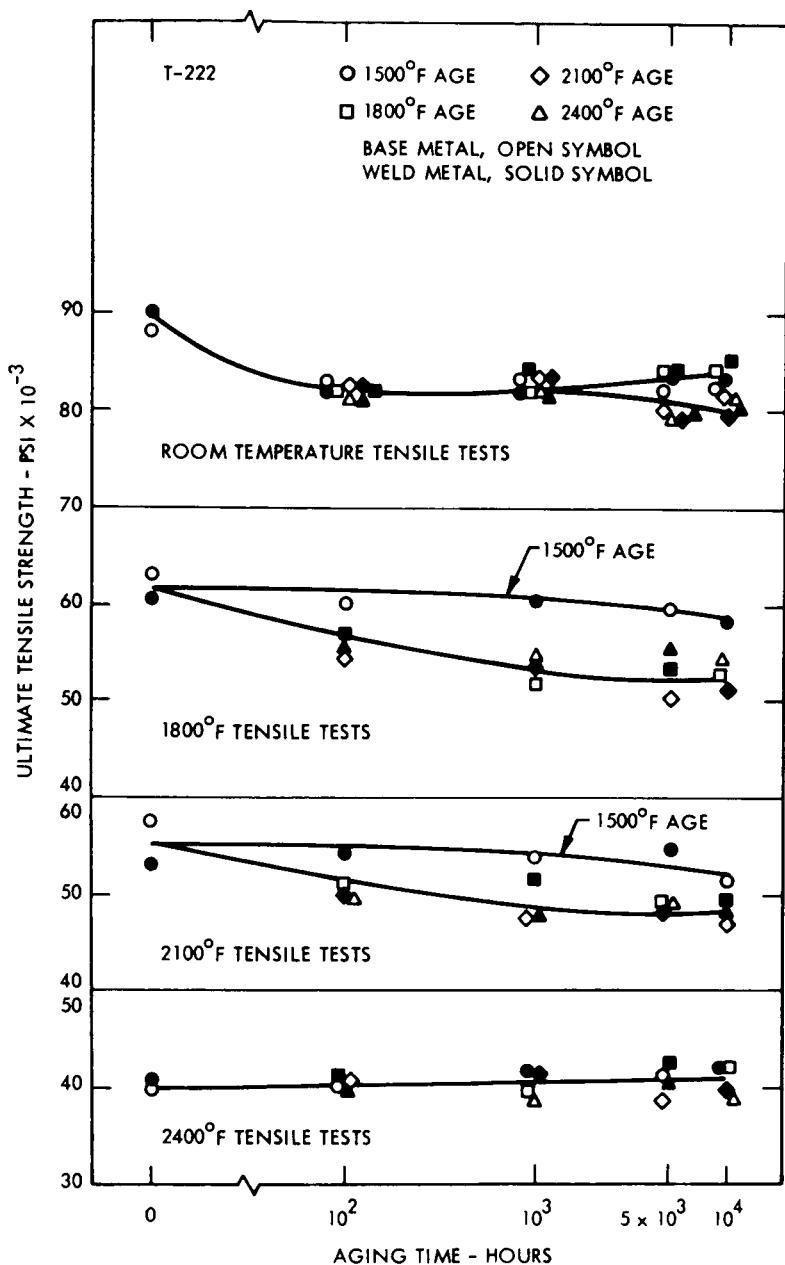
Unlike the tensile test results, determinations of the bend ductile-brittle transition temperature indicated a significant aging response for T-111, T-222 and FS-85, Figures 6, 7 and 8. Several similarities are noted for the three alloys:

- The magnitude of the response is greatest for gas tungsten arc welds and least for base metal specimens.
- Ductility is not impaired by aging at 2400°F.



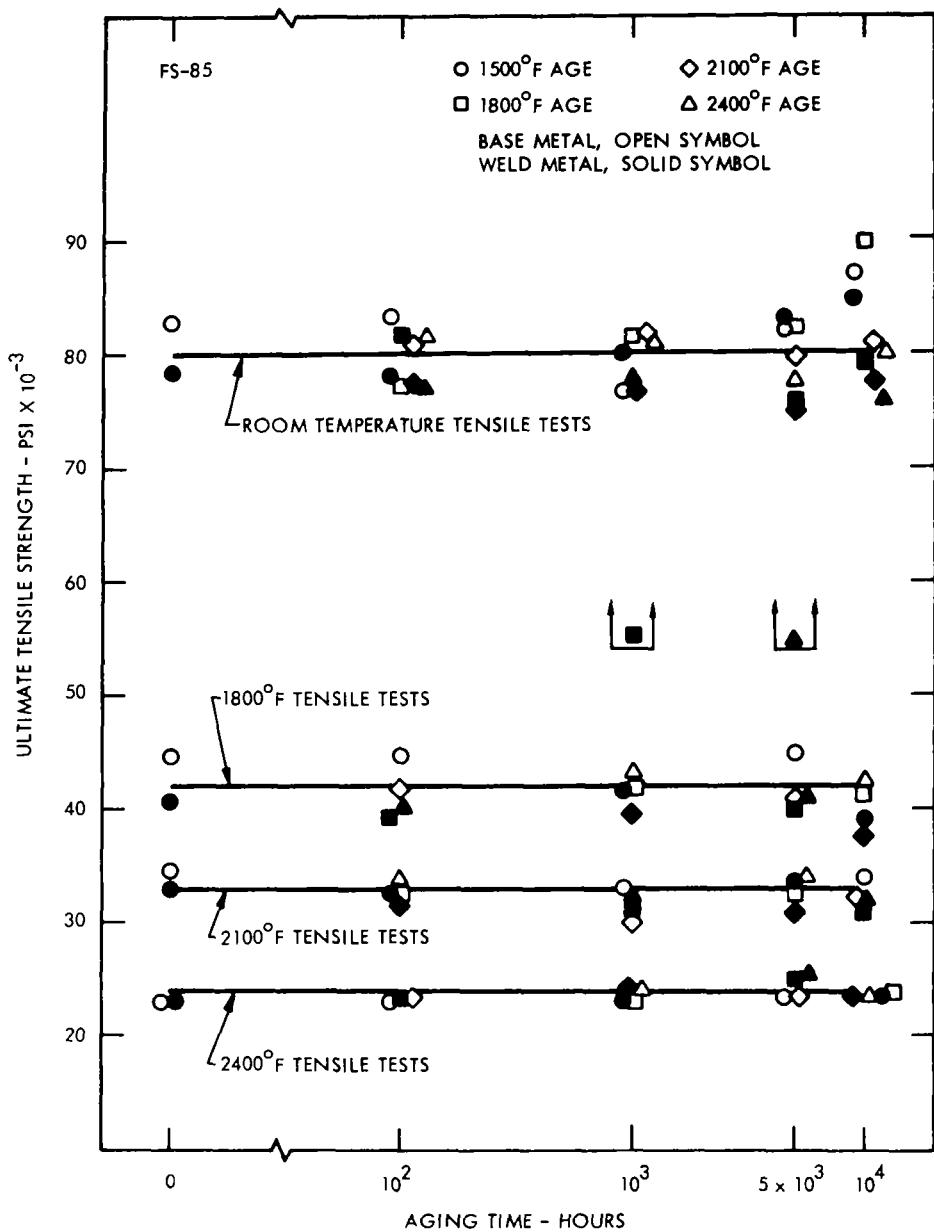
NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hr. at 2400°F Prior to Aging and Testing.

FIGURE 3 - Ultimate Tensile Strength of T-111 as a Function of Aging Parameters



NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hr. at 2400°F Prior to Aging and Testing.

FIGURE 4 – Ultimate Tensile Strength of T-222 as a Function of Aging Parameters



NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hr. at 2400° F Prior to Aging and Testing.

FIGURE 5 – Ultimate Tensile Strength of FS-85 as a Function of Aging Parameters

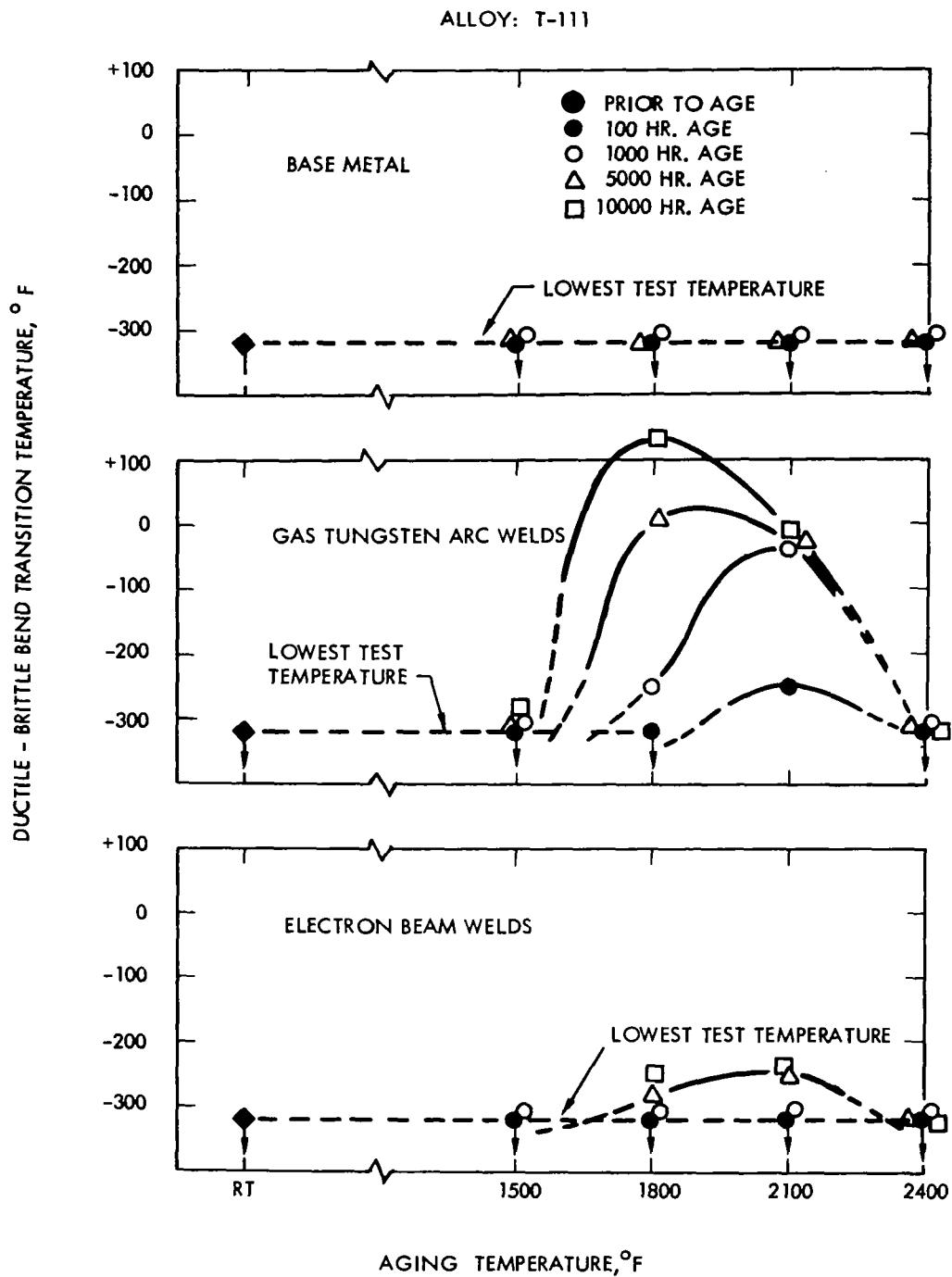


FIGURE 6 - Bend Ductile-Brittle Transition Temperature of T-111 as a Function of Aging Parameters (1t Bend Radius)

ALLOY : T-222

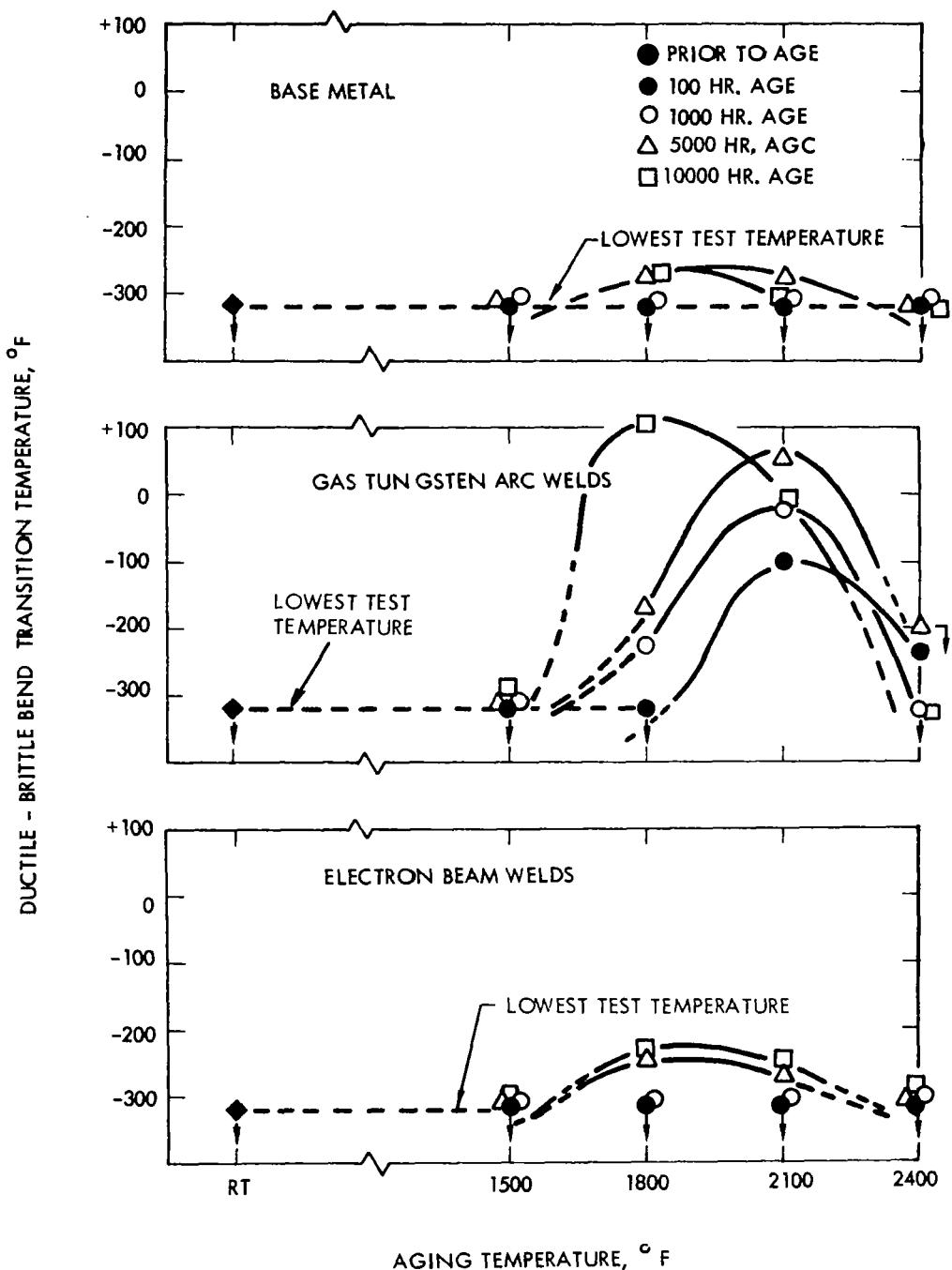


FIGURE 7 - Bend Ductile-Brittle Transition Temperature of T-222 as a Function of Aging Parameters (1t Bend Radius)

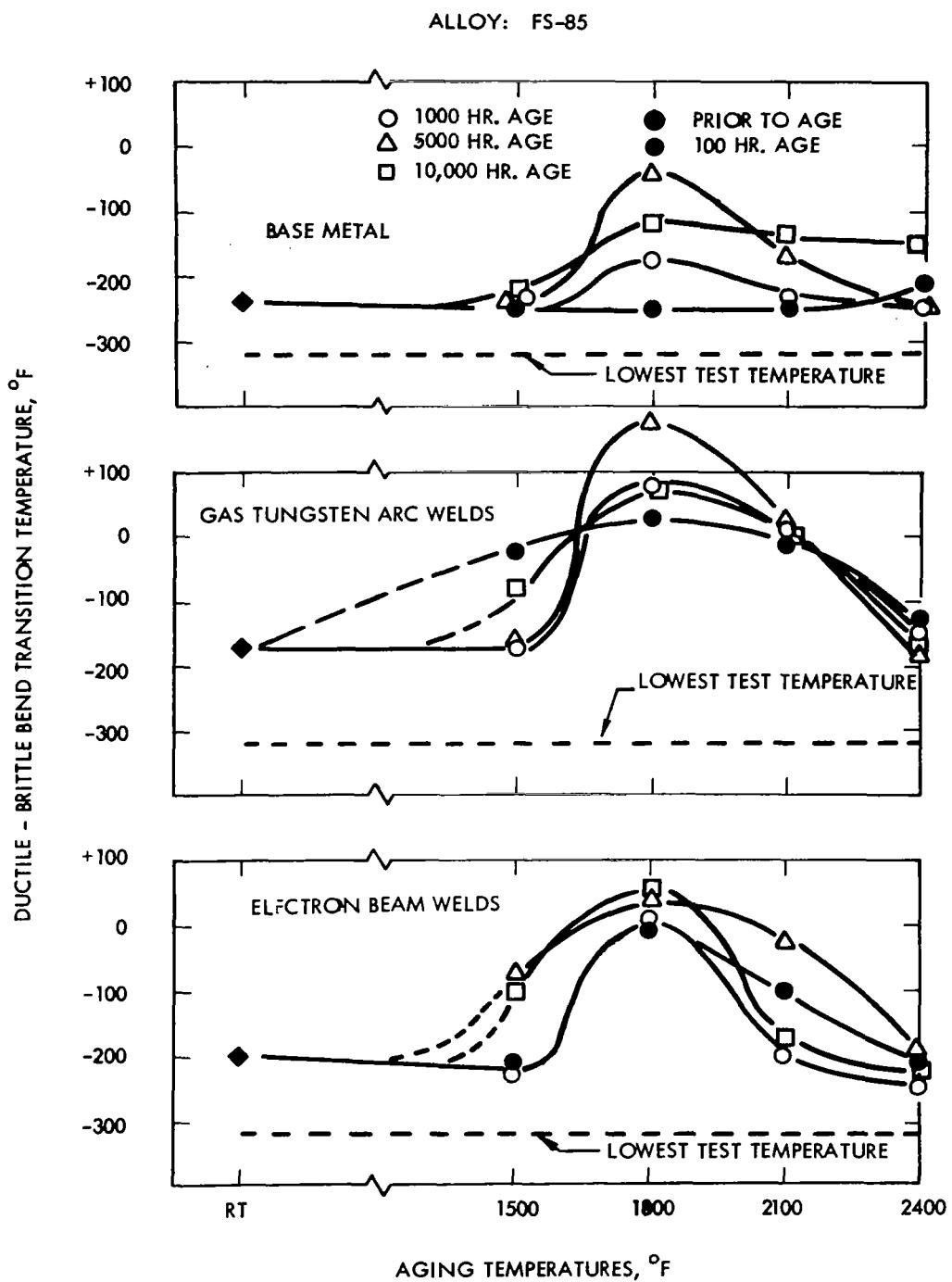


FIGURE 8 - Bend Ductile-Brittle Transition Temperature of FS-85 as a Function of Aging Parameters (2t Bend Radius)

- Aging at 1500° F caused no discernible effect in T-111 and T-222 but some response was noted for the lower melting, columbium-base FS-85.
- Maximum response for these alloys was after aging at 1800 and 2100° F.

NOTE: Subsequent to the aging study reported here, the aging response for T-111 received further scrutiny to more completely define its characteristics. (The details of this further effort are to be found in the Final Report on TASK V of this Contract. The abbreviated presentation of this work which follows is included only to complement the present discussion.) It was determined that T-111 weld aging was not responsive to post weld annealing to 3000° F. Hence, an overaged structure which would not respond to subsequent exposures at lower temperatures was not achievable using any practical annealing temperature. These results are shown in Figure 9. Further, the aging response as measured by the longitudinal tensile ductility of T-111 gas tungsten arc welds was not as severe as might be inferred from the bend test data. This is shown in Figure 10 for tensile tests run at 32° F. The welds all have good ductility but less than that required to pass the 1t bend test of this study which produces 33-1/3% outer fiber strain. In this respect the bend test should always be viewed as a go-no go test for a given level of strain. Figures 9 and 10 show that no thermal solution to aging could be achieved in this alloy and also that based on tensile ductility no solution was required. However, the necessity to understand the observed aging response could not definitely be dismissed. Hence, a considerable effort was expended to identify the mechanism responsible for the observed aging response. It does not appear that the observed aging compromises the use of T-111. This stems from the fact that all tantalum alloy fractures occurred by intergranular tearing exhibiting considerable ductility.

T-111 (Ta-8W-2Hf)

T-111 responses were evaluated in greatest detail both because of its general importance and because the similarity of responses indicated that only one alloy of this group required detailed analysis. Microstructures of the weld zone, heat affected zone (HAZ) and base metal of selected T-111 specimens are shown in Figure 11. Gas tungsten arc welds are shown since these represent the condition of maximum response.

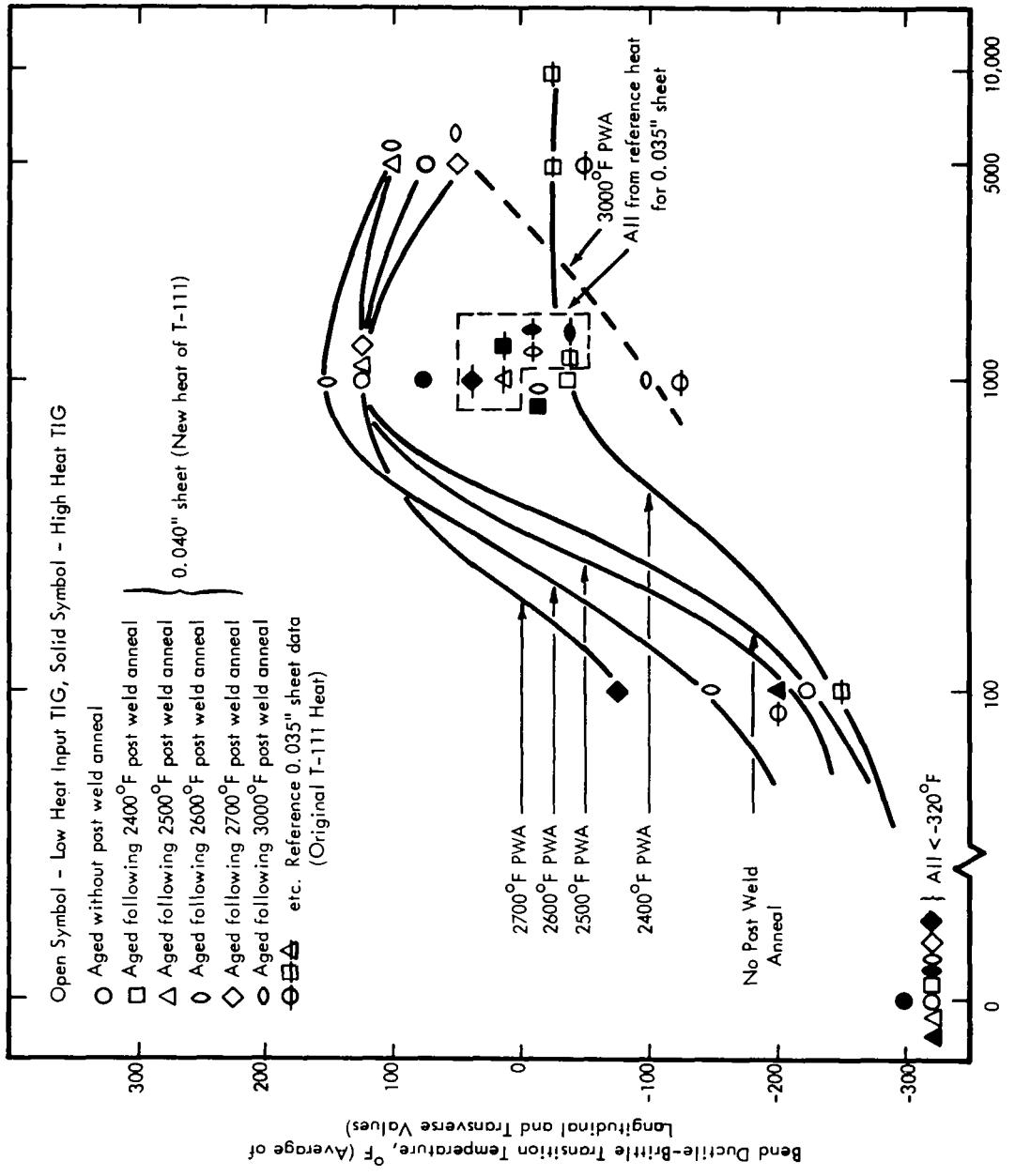


FIGURE 9 - Effect of Post Weld Annealing on Aging in T-111 Welds. Data Points Within Dashed Block for Tests on T-111 Heat Used This Program. Remaining Points from Additional Heat of T-111.
(Low Heat Input Welds Made at 15 ipm ; High Heat Input Welds Made at 6 ipm)

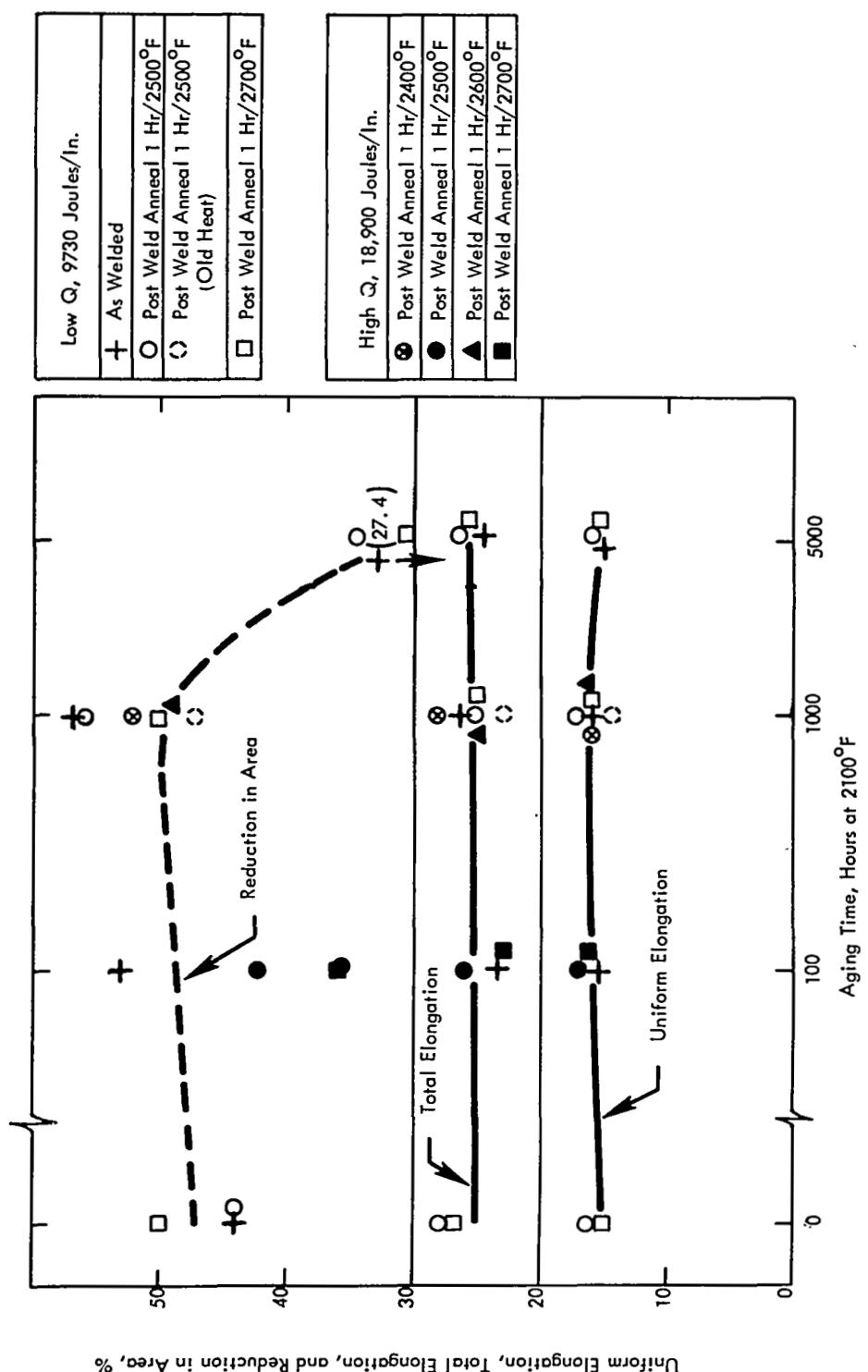


FIGURE 10 - T-111 Longitudinal Weld Tensile Ductility at 32°F after Aging as Indicated. Data for T-111 Heat Used This Study Except as Noted. (Low Heat Input Welds Made at 15 ipm; High Heat Input Welds Made at 6 ipm)

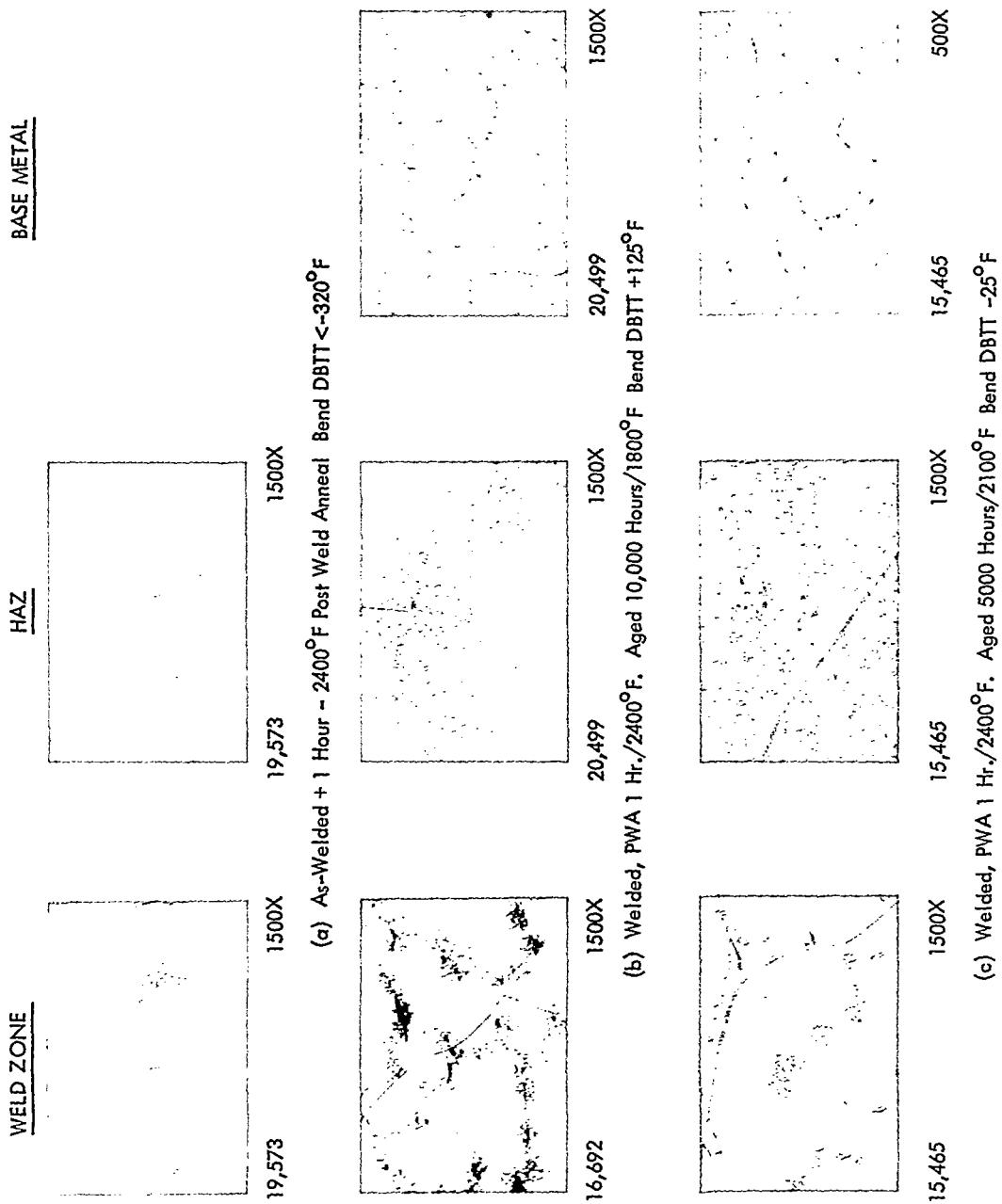


FIGURE 11 - Typical Microstructures of Weld, HAZ and Base Metal of T-111 GTA Weld Specimens as a Function of Post Weld Thermal History

The 1 hour- 2400°F post weld anneal, Figure 11a, has resulted in a weld zone relatively precipitate-free. In the HAZ the only evidence of precipitates is along the grain boundaries. The bend DBTT of this structure was below -320°F .

After aging for 10,000 hours at 1800°F the microstructure is altered from that of Figure 11a to that shown in Figure 11b. Weld zone precipitates can be observed in the aged structure, mainly along the interdendritic boundaries of the original cored weld structure. This suggests that gradients in solute concentration associated with the cored structure provide the driving force for this precipitation. There is, in addition, a nearly continuous precipitate phase located at the grain boundaries of the fusion zone. Fine, dispersed precipitates are apparent in the HAZ while the base metal appears to be quite clean except for the presence of coarse precipitates along the grain boundaries. The bend DBTT of this specimen was $+125^{\circ}\text{F}$.

The effect of aging T-111 at 2100°F for 5000 hours can be seen in Figure 11c. The amount of interdendritic precipitate has decreased while the amount of grain boundary precipitate in the fusion zone has remained relatively unchanged. Little change has occurred in the HAZ except that possibly a little more precipitation has occurred. The base metal, shown at 500X, is similar to that seen in Figure 11b. The bend DBTT is now -25°F .

After 10,000 hours at 2400°F , for which the bend DBTT was below -320°F , complete homogenization had occurred and, except for isolated, coarse precipitates at the grain boundaries, the structures were single phase. This structure could essentially be restored in specimens aged 10,000 hours at 1800°F by post age anneals of 1 and 16 hours at 2400°F . The microstructure of weld, HAZ and base metal following these anneals are shown in Figure 12. Comparison with Figure 11b indicates the post age anneals have effected a reduction in the amount of weld zone precipitates at both interdendritic and grain boundary areas and the nearly complete elimination of precipitates in the HAZ while having virtually no effect on the base metal. The post age annealed structure appears to be quite similar to the 1 hour- 2400°F post weld annealed structure of Figure 11a.

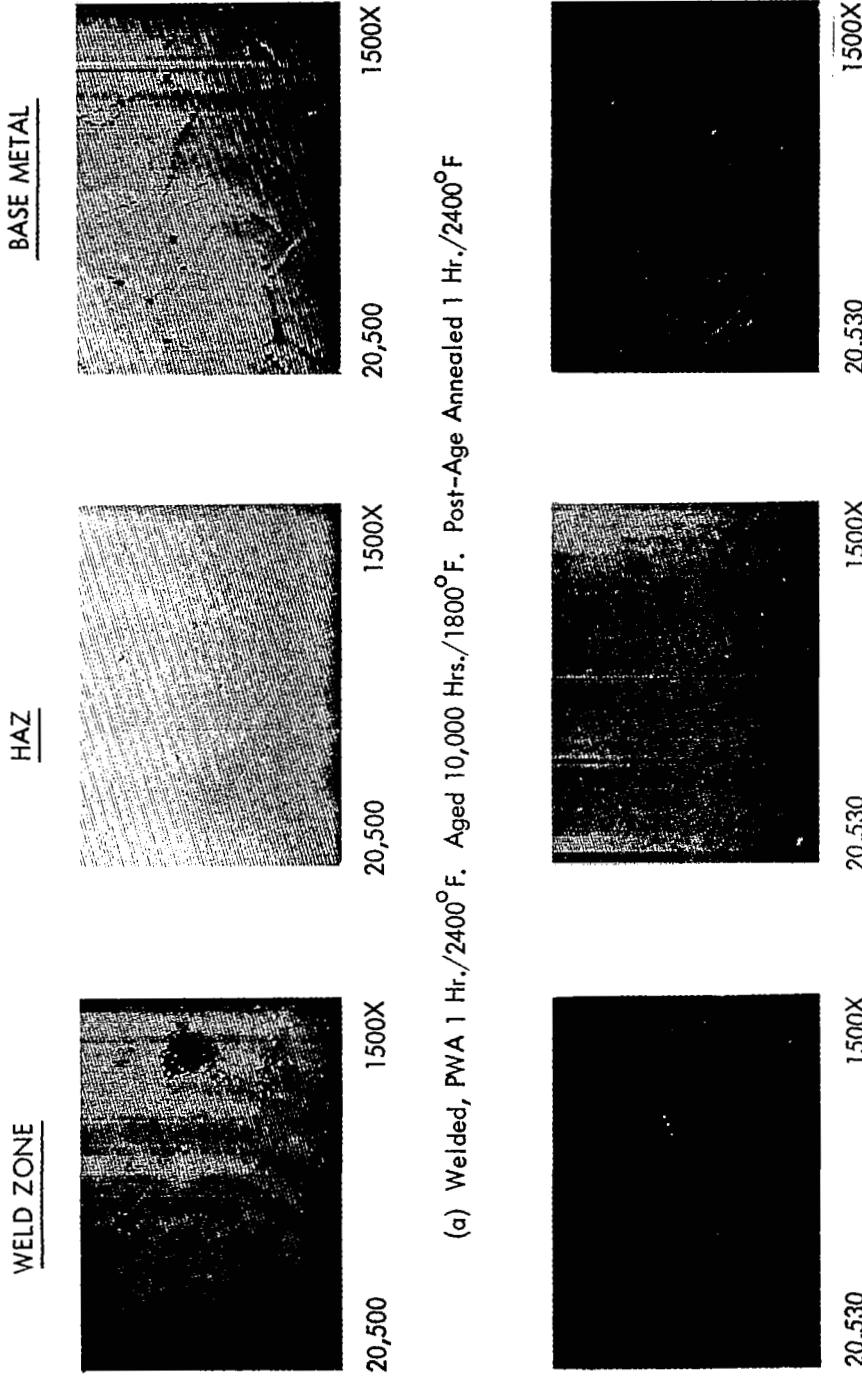


FIGURE 12 - Microstructures of T-111 After Indicated Post Age Anneals

There appears to be a correlation between the bend transition temperature and the amount of interdendritic and grain boundary precipitates in the weld fusion zone. Since the transition temperature decreases with a decrease in the amount of precipitate it seems likely that a cause-effect relationship exists between them. Further evidence of such a relationship, particularly in the case of the grain boundary precipitates, is the fact that weld fractures during bend testing were invariably intergranular. Hence, efforts were directed toward identification of the precipitates in order to obtain an understanding of the ductility impairment mechanism.

Bulk extraction residues were obtained from base metal and weld metal specimens of T-111 both before and after aging. Debye-Scherrer diffraction patterns of these residues indicated the presence of monoclinic HfO_2 , the FCC monocarbide $(\text{Hf}, \text{Ta})\text{C}$, and the dimetal carbide Ta_2C . The relative amounts of these phases did not vary significantly with specimen history. While these results are meaningful and useful it must be recognized there are a number of limitations of this technique. Some of these are:

- Some phases present may be attacked and dissolved by the bromine-methanol-tartaric acid solution used to dissolve the matrix.
- If a dispersed phase is present in a very small quantity it may be obscured by the background radiation.
- No information is obtained regarding the size, shape and distribution of the extracted particles.

To supplement the x-ray data selected area electron diffraction was performed on standard fractograph replicas of T-111 specimens aged as follows:

5,000 hours at 1800°F
10,000 hours at 1800°F
1,000 hours at 2100°F
5,000 hours at 2100°F

The fractograph replicas were prepared from the surfaces of freshly fractured specimens which were fractured by bending in a vise at -320°F. Standard replicating procedures were used except that shadowing was not employed since the primary aim was to ascertain the existence of, and to identify if possible, any particles which might be associated with the fracture surface. Examination with the electron microscope revealed second phase particles had been successfully retained on the replicas. Despite the fact high quality single crystal selected area electron patterns were obtained on a number of particles efforts to identify them were not successful. A typical electron micrograph and electron diffraction pattern are shown in Figure 13.

Additional extraction replicas were prepared from the fracture surfaces of GTA welds aged 1000 hours at 2100°F and 5000 hours at 1800°F. Platelet particles on these replicas were chemically analyzed at Advanced Metals Research Corporation using a focusing x-ray spectrometer attachment to a Philips EM-200 Electron Microscope. With this instrument the exciting electron beam can be focused to a diameter of about 1 micron on the surface of the specimen being analyzed. The chemical analysis of the excited area is afforded by analysis of the specimen's characteristic radiation by the x-ray spectrometer. Tantalum was the only metallic element found in the platelets analyzed. This suggests the platelets are light element compounds of tantalum such as carbides, oxides or nitrides.

To further characterize the weld zones and the effect of aging, electron microprobe techniques were employed to study microsegregation in GTA welds of T-111 in the as-welded plus 1 hour 2400°F post weld annealed condition and also in a similar weld aged 10,000 hours at 1800°F. The results of this work, also performed at Advanced Metals Research Corporation, are presented in Table 4.

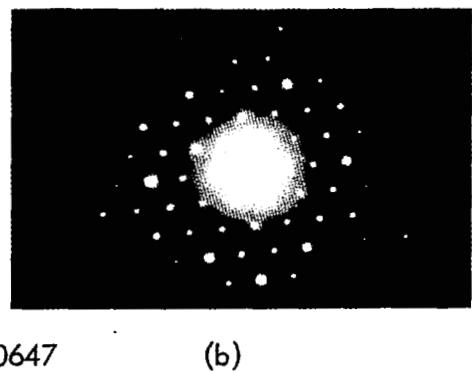
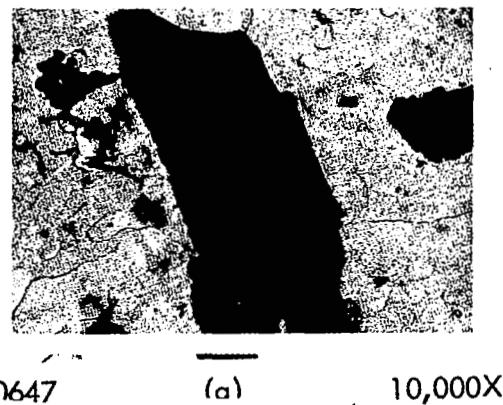


FIGURE 13 - Electron Micrograph (a) and Electron Diffraction Single Crystal Point Pattern (b) of Particle Extracted from T-111 Fracture Surface

TABLE 4 - Results of Electron Microprobe Study of Microsegregation in T-111 GTA Welds

Specimen Condition	Weld Region Analyzed(a)	Concentration (w/o)	
		W	Hf
As-Welded + 1 Hour 2400°F Post Weld Anneal	Near HAZ; IDB	7.9	3.1
	Near HAZ; IDI	9.6	1.7
	Weld Center; IDB	7.5	3.5
	Weld Center; IDI	9.8	1.3
As-Welded + 1 Hr. 2400°F + 10,000 Hrs. 1800°F	Near HAZ; IDB	7.8	4.5
	Near HAZ; IDI	10.1	1.9
	Weld Center; IDB	8.6	2.9
	Weld Center; IDI	9.6	1.9

(a) IDB - at the Interdendritic Boundaries
IDI - at the Interdendritic Interiors

These measurements indicate the magnitude of the coring which exists in the weld structure after the 1 hour 2400°F post weld anneal is being affected very little by 10,000 hour aging at 1800°F, an observation not unexpected since the kinetics of W and Hf diffusion would be quite slow at that temperature.

The results presented above indicate a case can be made for the existence of two different phases in the fusion zone. The observed W and Hf segregation indicates the interdendritic precipitates may be a heavy metal phase such as W_2Hf whereas the grain boundary phase is more likely a light element compound of tantalum. Observations of a decreasing amount of precipitate at both regions with higher aging temperatures is consistent with enhanced diffusion kinetics. The fact the fractures appear to be intergranular rather than interdendritic and the fact some aging response is observed in uncored base metal suggests that, if two different phases are involved, the grain boundary phase may be more important with respect to the aging response.

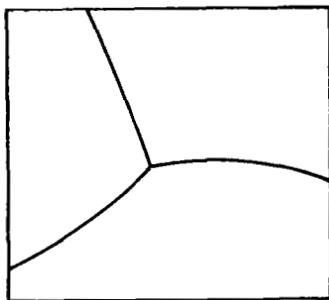
Briefly reviewing the precipitate behavior we find:

- (i) No evidence of the grain boundary precipitate is seen in the fusion zones of T-111 welds in either the as-welded or the as-welded and post weld annealed specimens. Modest interdendritic precipitation was noted (Figure 11a).
- (ii) Aging at 1800 and 2100°F results in precipitation on fusion zone grain and dendrite boundaries (Figure 11b and 11c).
- (iii) Short time annealing at 2400°F of welds aged at 1800 and 2100°F decreases the amount of both grain and dendrite boundary precipitate (Figure 12).

The fact the amount of precipitate observed after aging at 1800 and 2100°F is seen to decrease on subsequent exposure at 2400°F suggests a solvus temperature is being exceeded and the precipitate is going into solution.

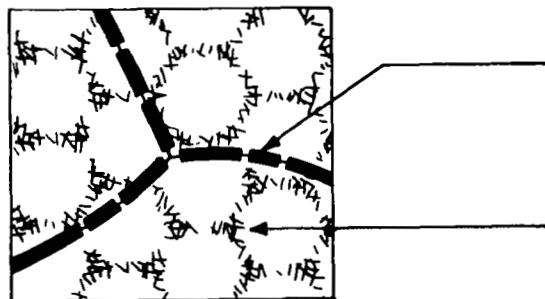
Hypothesis for the T-111 Aging Response

The 1800 to 2100°F reaction range suggests that the grain boundary precipitate is an interstitial compound behaving in a manner typified by Ta_2C . The interdendritic precipitate occurs simultaneously but in such large quantity and at a slower rate such that one is inclined to suspect this to be an intermetallic compound typified by W_2Hf . Neither was identified using the various experimental techniques of this program. However, the expected behavior of these two types of precipitates appears consistent with the observed aging response. The grain boundary precipitate exerts the most pronounced influence since the fractures were intergranular. The interdendritic precipitate probably has an indirect influence on the aging response. Its substructure-like arrangement could lead to strengthening within the weld grains. This would lead progressively to a greater differential between grain boundary and matrix strength forcing the grain boundaries to accommodate an increasingly larger share of the total strain with aging. This enhances the tendency for grain boundary failures, a failure mode already promoted in welds by their large grain size (and, hence, low total grain boundary area). This hypothesis is shown schematically in Figure 14.



WELD STRUCTURE PRIOR TO AGING

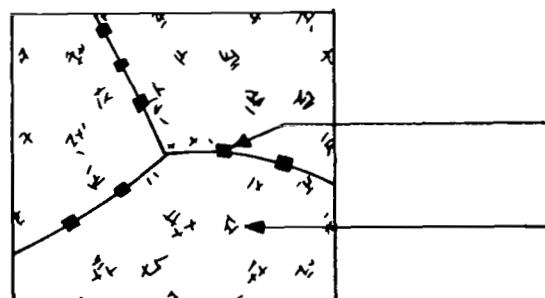
AFTER AGING AT 1800° to 2100°F



Grain Boundary Precipitate - believed to be an interstitial compound; behavior typified by that of Ta_2C .

Interdendritic Precipitate - believed to be an intermetallic compound such as W_2Hf ; large volume fraction, sluggish reaction. (Almost exact stoichiometric composition observed.)

AFTER SHORT TIME POST AGE ANNEALS AT 2400°F



Grain Boundary Precipitate - shown after nearly complete dissolution. Disappears before the interdendritic precipitate.

Interdendritic Precipitate - also shown prior to complete dissolution.

FIGURE 14 - Schematic Representation of Response of T-111 Weld Structure To Aging

The evidence suggesting the grain boundary precipitate to be an interstitial compound such as $Ta_2C^{(4)}$ is as follows:

- (i) Located preferentially at grain boundaries.
- (ii) Stable within the approximate aging temperature range.
- (iii) Unstable at or about $2400^{\circ}F$ (may transform and go into solution at this temperature).
- (iv) Primarily Ta-base (no W or Hf) as observed by x-ray spectrometry of the fracture surface compound.

The evidence suggesting the presence of an intermetallic phase (such as W_2Hf) at the interdendritic boundaries is as follows:

- (i) The observed sluggishness in formation is typical of an intermetallic compound.
- (ii) The large volume fraction of interdendritic precipitate seems to preclude the possibility it is an interstitial compound.
- (iii) Solute redistribution to dendrite boundaries, as determined by electron beam microprobe analysis, results in W and Hf concentrations nearly stoichiometric with W_2Hf .

The compromising evidence for this hypothesis includes:

- (i) Neither the grain boundary phase nor the interdendritic phase was positively identified. Ta_2C was detected by x-ray diffraction of bulk extraction residues but could not be definitely associated with the grain boundaries. Extraction of the intermetallic would be particularly difficult.
- (ii) Phase relationships for W_2Hf in the ternary system are not known.

Other possibilities which were considered but seem to be precluded by the experimental evidence include:

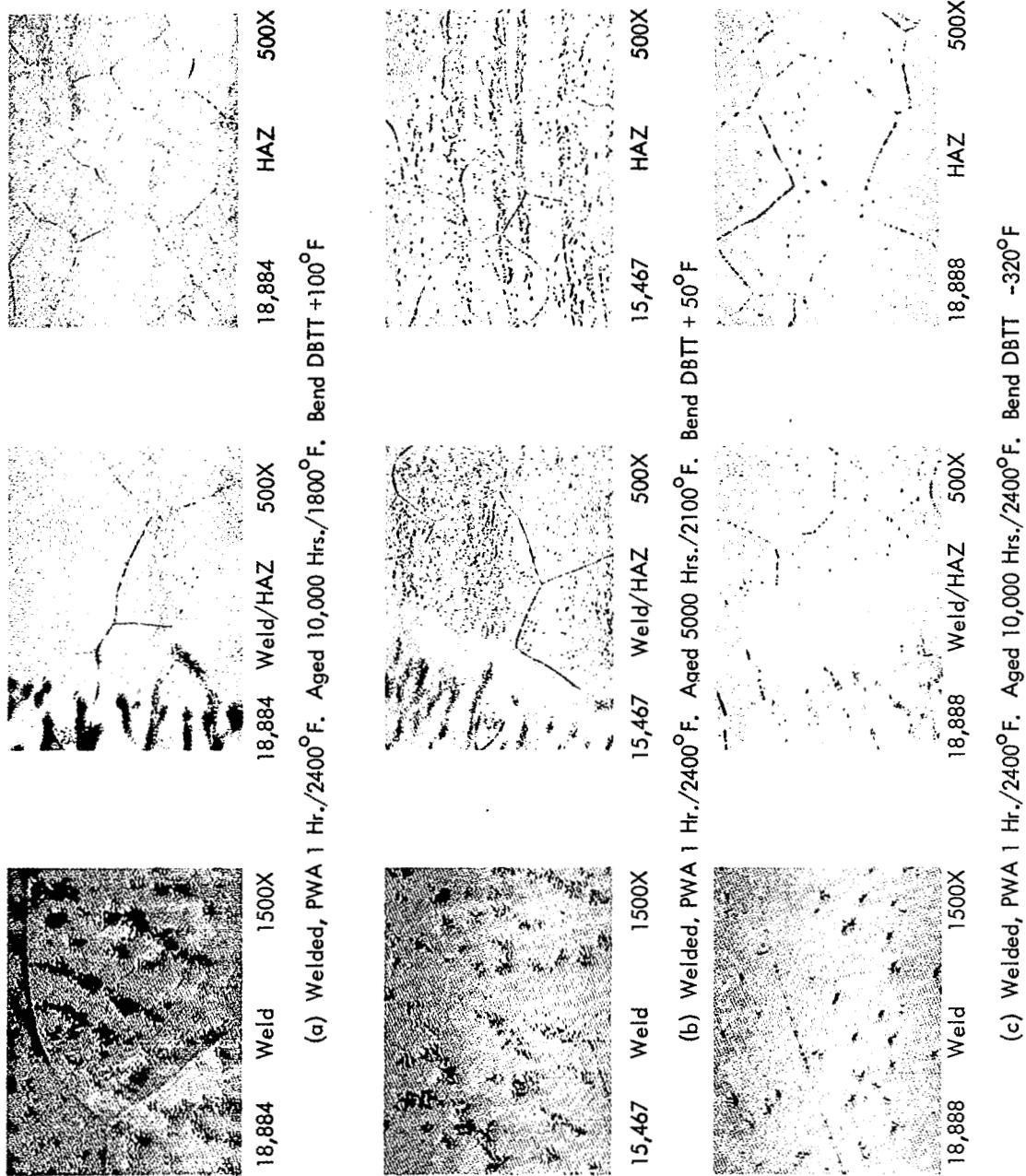
- (i) That the grain boundary precipitate is the MC phase (or some analogous phase), since this phase invariably is Hf-rich, a possibility refuted by the results of the x-ray spectrometry. Also, MC exhibits no preference for grain boundary precipitation.
- (ii) That the interdendritic phase is a complex Ta-Hf compound forming due to the β' - β'' miscibility gap known for this alloy system. For such a reaction to occur an enormous local concentration of Hf (>30%) would be required.
- (iii) That either the interdendritic or the grain boundary phase is HfO_2 since this compound, both in the monoclinic and cubic forms, is easily and routinely extracted and its concentration determined using bulk diffraction techniques. The HfO_2 concentration did not vary with location or aging conditions.

T-222 (Ta-9.6W-2.4Hf-0.01C)

The aging response of this alloy as revealed by changes in the bend transition temperature was similar to that of T-111. The rationale developed and presented for T-111 extends quite well to T-222, requiring only minor modification.

Typical microstructures of T-222 welds aged at 1800, 2100 and 2400°F are shown in Figure 15. Comparison of Figure 15a to Figure 11b reveals that, after 10,000 hours at 1800°F the aging reaction has resulted in a substantially greater amount of both grain boundary and interdendritic precipitation in T-222 than occurred in T-111. This was not an isolated case but was true for most aging conditions. The greater amounts of precipitate formed by the 1800 and 2100°F aging coupled with the fact the carbon level was apparently greater than the 2400°F solubility limit in the alloy resulted in residual precipitates being apparent in the structures aged 10,000 hours at 2400°F. The intragranular precipitates observed in the HAZ regions in Figures 15a and 15b appear to be those identified by Ammon and Harrod⁽⁴⁾ as the Hf-rich monocarbide, $(\text{Hf}, \text{Ta})\text{C}$. After 10,000 hours at 2400°F this carbide appears to be undergoing coarsening.

FIGURE 15 – Typical Microstructures of Selected T-222 GTA Weld Specimens as a Function of Post Weld Thermal History



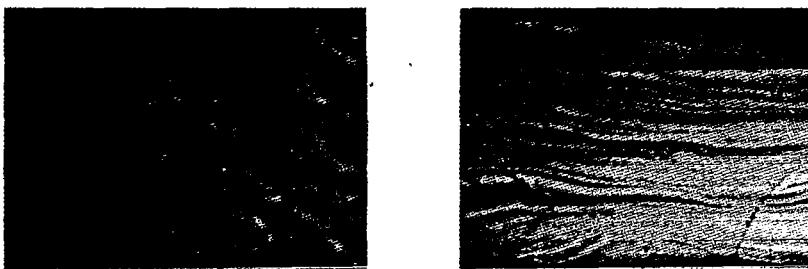
Efforts at phase identification were much more limited for this alloy than for T-111. However, the similarity of aging response, microstructural features, and fracture behavior suggest only modest revision of the hypothesis presented for T-111 would be required for T-222.

FS-85 (Cb-27Ta-10W-1Zr)

While the aging response of this columbium-base alloy was generally similar to that of T-111 and T-222 several important differences were noted in the bend test results. The fracture mode of this alloy was generally by brittle cleavage and not by ductile grain boundary tearing as was noted for T-111 and T-222. An apparent effect of this failure mode was that fractures in weld specimens were not arrested in the base metal. Further, this fracture mode probably accounts for the increased response of base metal and electron beam welds to aging as compared with T-111 and T-222. This fracture behavior is typical of columbium-base alloys, and does not in itself imply any difference with respect to the aging mechanism of this alloy. Finally, FS-85 responded to aging at a lower temperature than T-111 or T-222, perhaps explained in part by its lower melting point.

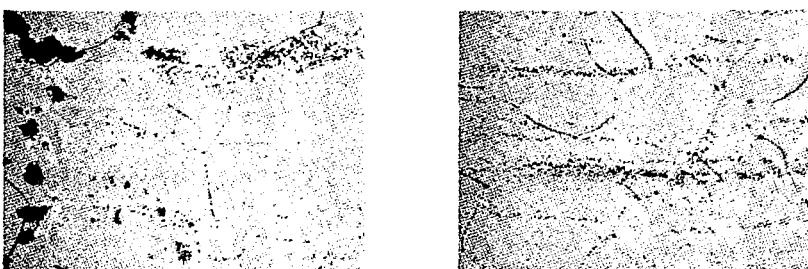
Microstructures of FS-85 are shown in Figure 16 for several aging conditions. In Figures 16b and 16c the interdendritic precipitate is visible in the weld zone. For most aging conditions there appeared to be less grain boundary and interdendritic precipitation than was observed in comparably aged T-111 and T-222.

In FS-85, zirconium is the reactive metal addition which behaves in a manner analogous to that of hafnium in tantalum-base alloys. However, in FS-85 there is only about 1 a/o Zr whereas the tantalum-base T-111 and T-222 alloys contain approximately 2.0 and 2.4 a/o Hf, respectively. One might reasonably expect then that the zirconium enrichment at interdendritic boundaries in FS-85 welds does not approach the hafnium enrichment in T-111 and T-222 welds. In addition, the carbon level of the FS-85 sheet used for this program was notably less (in terms of atomic ppm) than that of either tantalum-base alloy. Both of these conditions would tend to decrease, relative to T-111 and T-222, the amount of interdendritic and grain boundary precipitate in the fusion zones.



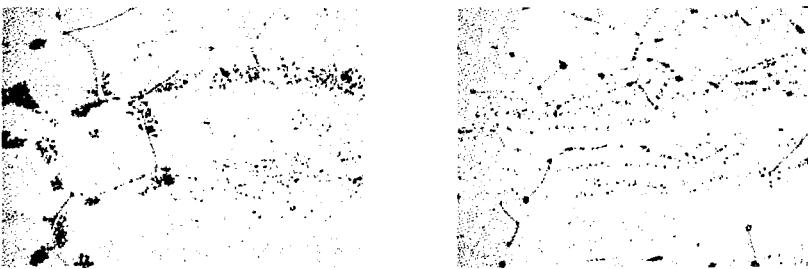
15,140 Weld 1000X 15,140 Base Metal 1000X

(a) Welded, PWA 1 Hr./2400°F. Aged 1000 Hrs./1500°F.
Bend DBTT -175°F



15,460 Weld/HAZ 500X 15,460 Base Metal 500X

(b) Welded, PWA 1 Hr./2400°F. Aged 5000 Hrs./1800°F.
Bend DBTT +175°F



18,872 Weld/HAZ 500X 18,872 Base Metal 500X

(c) Welded, PWA 1 Hr./2400°F. Aged 10,000 Hrs./1800°F
Bend DBTT +75°F

FIGURE 16 - Typical Microstructures of FS-85 GTA Weld Specimens
as a Function of Post Weld Thermal History

Note the hypothesis presented for T-111 can be extended quite well to FS-85 since W₂Zr and Cb₂C provide direct analogs to W₂Hf and Ta₂C. In view of the differences in the amount of precipitate between FS-85 and T-111 it may not be possible to ascribe the exact same rationale to their respective aging responses. Admittedly there are two possible explanations which could account for the similarity in behavior in spite of the microstructural differences:

1. A very small volume of precipitate is required to control the observed aging response in that FS-85 fractured largely by brittle cleavage.
2. The similarity may be strictly fortuitous. The response observed in the bend transition temperature may be reflecting the bulk or net change of a number of complex interacting factors.

Following 2400°F aging, for which microstructures are not shown, considerable grain growth had occurred, weld zones could no longer be distinguished from HAZ and base metal, and very little evidence of precipitates remained. The fact the bend DBTT was about -150°F to -175°F for all types of test specimens after aging 10,000 hours at 2400°F implies a ductility limit due to grain size has been realized.

OTHER SOLID SOLUTION + DISPERSION STRENGTHENED ALLOYS (B-66, D-43, Cb-752, C-129Y)

B-66 (Cb-5Mo-5V-1Zr)

Considerable grain growth and modest changes in mechanical properties marked the response of B-66 to long time, elevated temperature aging. Base metal, GTA welds and EB welds were aged for times to 10,000 hours and temperatures to 2400°F.

Almost without exception, the results of tensile tests and bend DBTT tests could be interpreted in terms of grain size of the test specimens. Most of the aging temperatures employed in this study are quite high for this alloy and the large grain sizes noted in the post-age microstructures are not unexpected. Changes in ultimate and yield tensile strengths at R.T., 1800, 2100 and 2400°F were quite modest due to the thermal exposures.

The only significant exception to the above rationale would appear to be the slight "peak" in the bend DBTT found for GTA welds after 1500°F aging, Figure 17. That this peak diminishes with increased aging time at 1500°F suggests the possibility that a classic precipitation reaction is occurring. By 5,000 hours the overaged condition has apparently been attained and no ductility loss is apparent from the bend test results. Program emphasis did not allow further definition of this reaction but the slight improvement in room temperature yield strength for specimens aged at 1500°F relative to the other aging temperatures lends credence to this suggestion. After 5,000 hours of aging, ductility of base metal and EB welds normalized to that of GTA welds, an effect easily explained in terms of grain size.

Like other columbium alloys this alloy displayed a classic abrupt transition in bend testing from ductile-to-brittle behavior.

D-43 (Cb-10W-1Zr-0.1C)

This carbide-dispersion strengthened alloy provided the prime example of classic overaging and subsequent loss of strength of the alloys included in the aging study. This alloy has been the object of considerable metallurgical interest, primarily because of its aging reactions. As a result, extensive investigations of these reactions have led to a unique, for refractory metal alloys, and precise identification of the various reaction stages and products. The work of Ostermann and Bollenrath⁽⁵⁾ is particularly outstanding in this respect.

The ultimate tensile strength as a function of aging time and temperature for base metal and GTA welds is shown in Figure 18 for tensile tests conducted at room temperature, 1800, 2100, and 2400°F. That only overaging behavior is observed is believed due to an apparent optimum condition achieved in the as-received D-43 sheet using a 2400°F post weld anneal. The microstructure of the base metal, as viewed by light microscopy at 1500X, changed very little from that of the as-received sheet throughout aging treatments as long as 10,000 hours

ALLOY: B-66

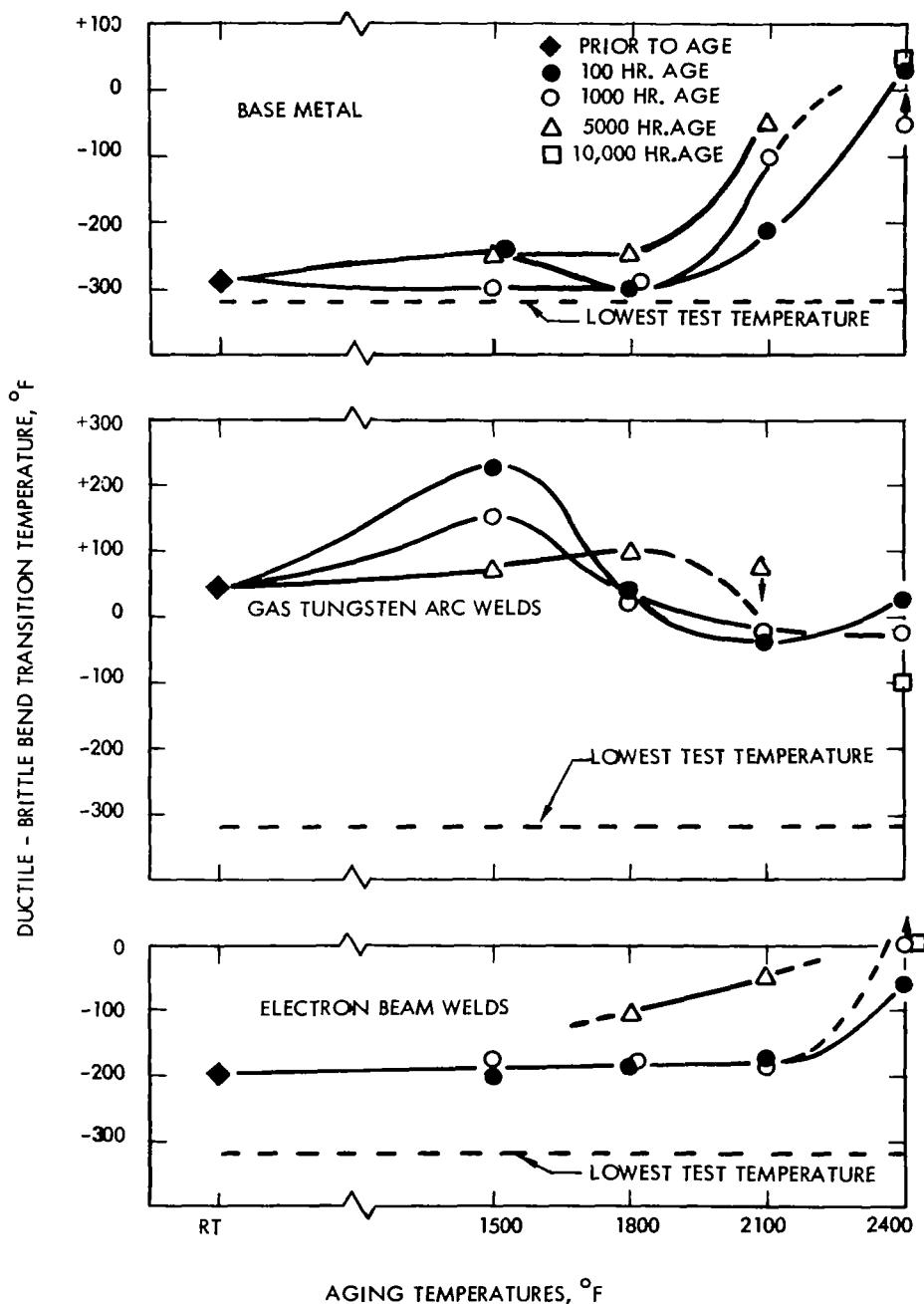
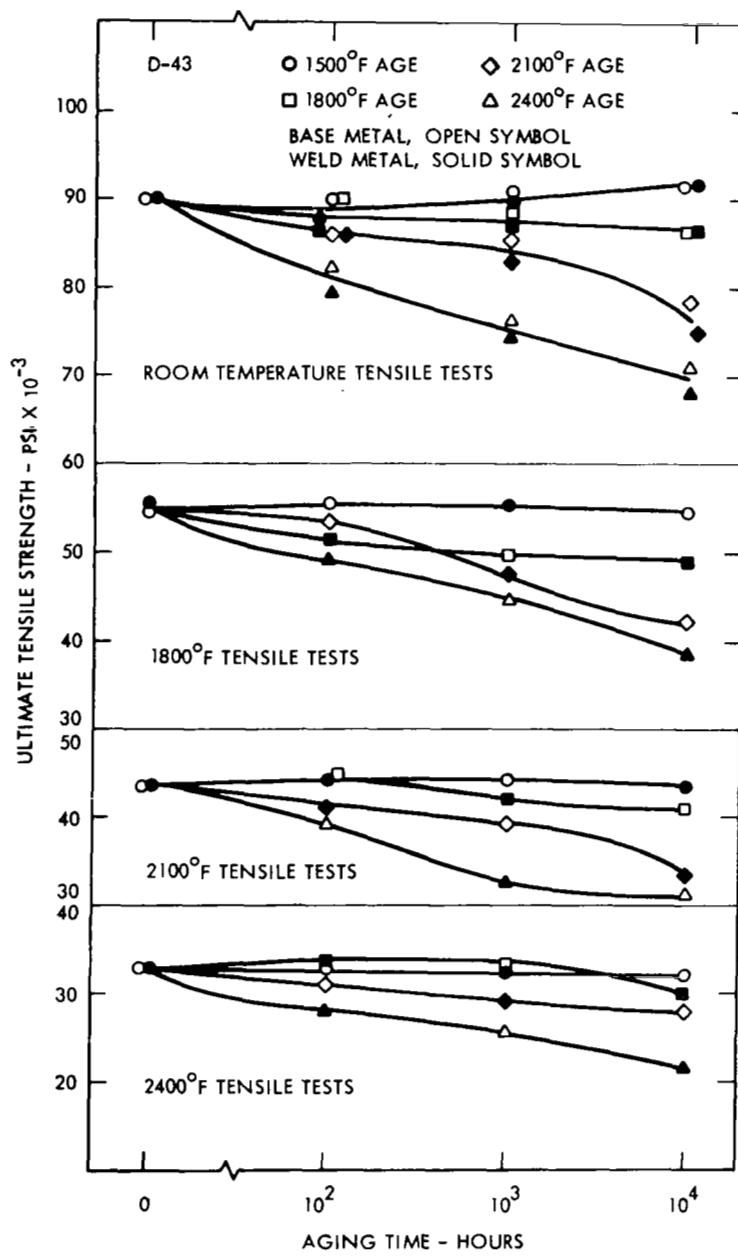


FIGURE 17 - Bend Ductile-Brittle Transition Temperature of B-66 as a Function of Aging Parameters (1t Bend Radius)



NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hr. at 2400°F Prior to Aging and Testing.

FIGURE 18 - Ultimate Tensile Strength of D-43 as a Function of Aging Parameters

at 1800°F, being comprised of a very fine (Cb,Zr)C precipitate dispersed throughout the grain interiors and a coarser columbium carbide, Cb₂C, present as intragranular platelets and a grain boundary precipitate.

The microstructure of the base metal following 10,000 hour aging at 1800 and 2100°F is shown in Figure 19 along with representative weld heat-affected-zone (HAZ) areas for each of these aging conditions. In the base metal both the fine (Cb,Zr)C precipitates and the Cb₂C precipitates have coarsened somewhat during the long-time aging at 2100°F relative to those resulting from aging at 1800°F or lower. The reaction in the HAZ regions is quite different from that occurring in the base metal. During welding, complete solutioning occurs in the HAZ and, because of the rapid cooling to temperatures below about 1000°F, rejection of carbon from solid solution results in the formation of metastable ϵ carbides. These carbides are unstable at higher temperatures and transform to the hexagonal Cb₂C and the cubic (Cb,Zr)C, the relative amounts of which depend on temperature of transformation. Hence, the carbides in the HAZ following 10,000 hour aging at 1800°F appear to be a mixture of ϵ -carbide and Cb₂C while after 10,000 hours at 2100°F they are a mixture of Cb₂C and cubic (Cb,Zr)C.

The precipitate-free zones adjacent to grain boundaries which are apparent in Figure 19, particularly following the 2100°F aging treatment, are probably indicative of carbon and/or vacancy depletion of the matrix due to interstitial and/or vacancy diffusion to grain boundaries. While solute depletion of the matrix by diffusion of Zr (or W) could lead to the same type of structure the relatively low aging temperature renders this much less likely.

The overaged condition implied by the tensile data of Figure 17 for a base metal specimen aged 10,000 hours at 2400°F is shown in Figure 20.

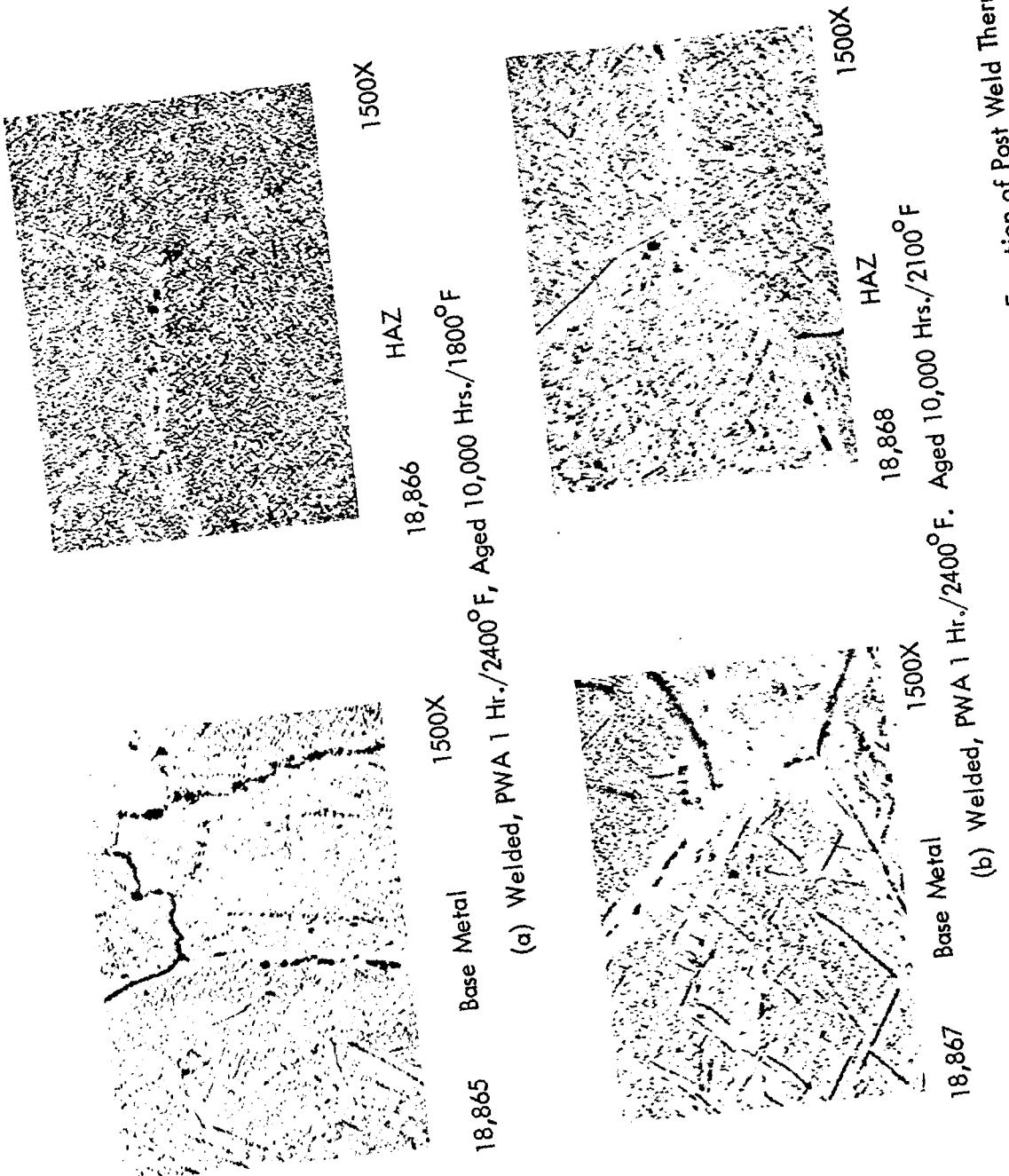
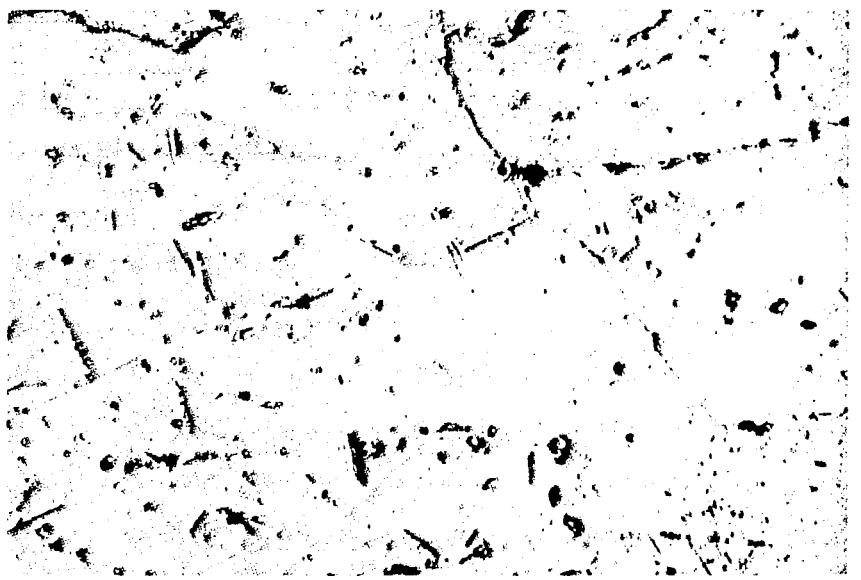


Fig. 10 - Microstructures of D-43 GTA Weld Specimens as a Function of Post Weld Thermal History



18,869

1500X

FIGURE 20 - D-43 Base Metal Aged 10,000 Hours at 2400°F

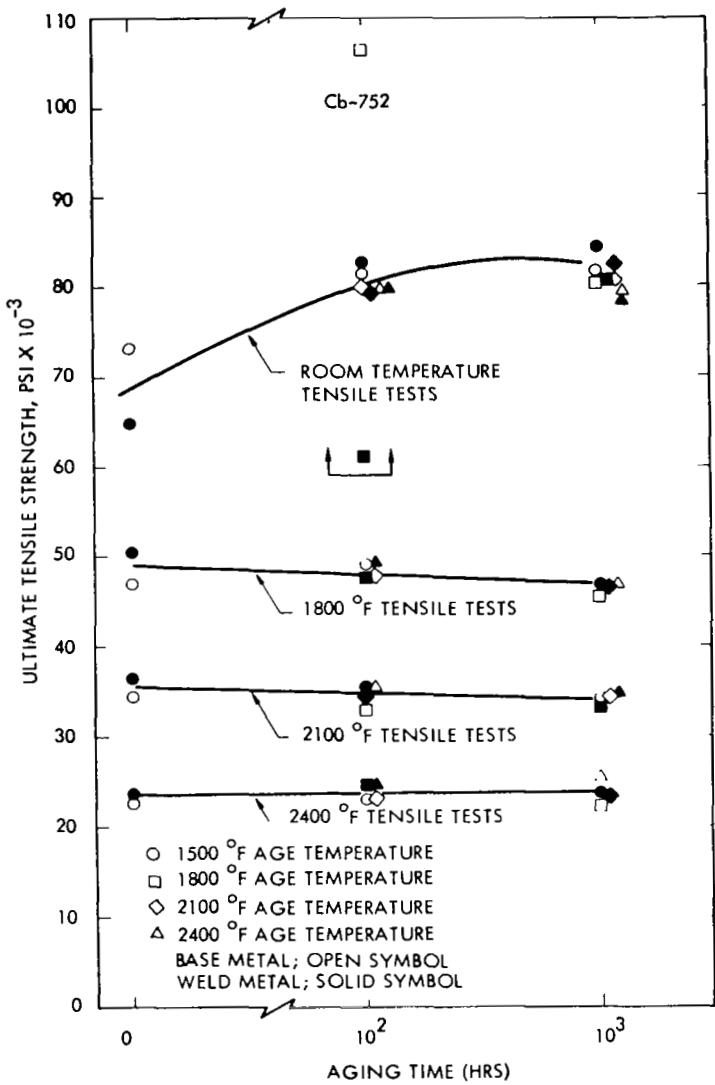
The bend DBTT data followed the trend established by the tensile data in that, for nearly every aging condition, the aging process increased the ductility (i.e., lowered the bend DBTT). Hardness traverses of aged specimens were of little value as indicators of the aging process. Bend transitions were generally abrupt changes from ductile-to-brittle behavior as characteristic of columbium base alloys.

From this screening study it would appear the instabilities in structure and mechanical properties of D-43 which result from aging warrant careful consideration for applications involving long times at temperatures above 1500° F.

Cb-752 (Cb-10W-2.5Zr)

The response of this alloy to 1,000 hour exposures at temperatures from 1500 to 2400° F was somewhat random. Bend DBTT tests indicated slight, irregular changes with aging temperature. Fracture behavior was typical of columbium alloys. The general trend however was for an improvement in bend ductility for specimens aged at 2400° F. Results of tensile tests indicated that, except for room temperature ultimate and yield strength, aging time and temperature had very little effect. In Figure 21, the room temperature strength is seen to improve while the elevated temperature strength is relatively unaffected by the aging.

Cb-752 is reported to achieve optimum tensile strength through the use of a duplex annealing treatment during processing⁽⁶⁾. This treatment consists of a 1 hour-2800° F solution anneal followed by a final cold reduction (40%) and a 1 hour-2400° F aging anneal. The final anneal is used to induce (Zr,Cb)C precipitation which provides dispersed phase strengthening. The Cb-752 sheet evaluated in this aging study was produced by a previous processing schedule which did not incorporate an in-process solution anneal and used a 1 hour-2200° F final anneal. Hence, the program Cb-752 was presumably not in the optimum condition with respect to mechanical strength. Comparing the data of Figure 21 with that of Bewley⁽⁶⁾



NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hr. at 2200°F Prior to Aging and Testing.

FIGURE 21 - Ultimate Tensile Strength of Cb-752 as a Function of Aging Parameters

indicates the following:

- The unaged R.T. tensile strength found in this study is noticeably lower than that attained using the duplex annealing treatment.
- Following the 100 and 1,000 hour aging at elevated temperatures, the tensile strengths determined in this study (Figure 21) are identical with those expected for similarly aged, duplex annealed sheet.
- Elevated temperature tensile strength of the program Cb-752 (base metal and GTA welds) is approximately equal to that indicated for duplex annealed sheet.

Similar observations apply to the respective yield strength data.

These results imply that, at least with respect to the factors affecting mechanical strength, very little difference exists between the Cb-752 evaluated in this program and that produced by duplex annealing. The only notable exception appears to be the inferior unaged room temperature strength of the sheet used for this evaluation. This is probably due to the lack of an in-process solution anneal and the use of a lower final annealing temperature for the program Cb-752. Both of these would detrimentally affect the amount and distribution of the strengthening precipitates and would therefore contribute to the observed deficiency in room temperature tensile strength.

C-129Y (Cb-10W-10Hf-0.1Y)

Thermal exposures to 1,000 hours at 2400° F had no discernible effect on the tensile properties of this alloy while data from bend DBTT tests indicated some minor, non-general responses to aging had occurred. In typical fashion, the greatest response was seen in gas tungsten arc welds. Fracture behavior was again typical of columbium alloys.

Metallographic examination of aged specimens indicated the grain refining effect of the yttria was effective in controlling grain size of the base metal. Conversely, loss of yttria during welding is implied by continuous grain growth which occurs in the weld fusion zones as a function of the severity of thermal exposure.

SOLID SOLUTION ALLOYS (Ta-10W, SCb-291)

General

The solid solution alloys included in this study were SCb-291 (Cb-10W-10Ta) and Ta-10W. For moderate temperature applications these alloys can be expected to perform adequately for extended periods of time. For the purposes of this program, however, their inclusion is mainly to provide base-line data to permit discrimination between those effects due to solid solution strengthening and those due to dispersed phase strengthening in more complex alloys. Alternatively, since these alloys should be very stable, they also acted as "referee" alloys to double check the aging and handling procedures. Their stable responses to aging did in fact demonstrate the adequacy of the experimental procedures.

Ta-10W

No instability in structure or tensile strength resulted from 1,000 hour exposures at temperatures to 2400°F. Bend transition temperatures of base metal, GTA welds and EB welds were <-320°F for all aging conditions. Microstructures in every case were single phase. Weld structures, particularly GTA welds, were characterized by extremely large grains which resulted in rather low tensile elongation during tensile testing. However, this behavior was in no way influenced by the aging but rather was a property of the weld structure.

SCb-291 (Cb-10W-10Ta)

This Cb-base alloy demonstrated excellent thermal stability for all aging time-temperature conditions evaluated. Aging was not performed beyond 1,000 hours. Tensile properties showed no significant changes due to the thermal exposures. Bend transition temperatures

were generally unaffected by aging except for a slight lowering of bend ductility following the 1,000 hour exposures at the highest aging temperatures. Fracture mode in bend testing was brittle cleavage so that bend transitions always occurred with a classic change from ductile-to-brittle behavior. Subsequent metallography indicated this to be the result of the considerable grain growth which occurs at the most severe thermal exposures. Microstructures were single phase in all cases. Grain growth appeared to be a continuous process as expected for a single phase, solid solution alloy.

In conclusion, SCb-291 offers excellent structural and mechanical property stability following long time elevated temperature exposures. Its usefulness, however, is limited by its relatively low high temperature strength.

IV. CONCLUSIONS

1. The alloys evaluated displayed a wide range of responses to the thermal exposures employed in this program. In most cases, these responses were most easily understood in terms of the metallurgy of the respective alloy system.
2. The alloys generally displayed satisfactory stability as would typically be required for engineering applications. However, several alloys are temperature limited with respect to thermal stability. D-43 displayed loss of strength with increasing aging time and temperature. This would have to be accommodated in setting design stresses for long time applications for temperatures above 2000°F. SCb-291 and B-66 were prone to loss of ductility with increasing grain size caused by high temperature aging. Hence, these alloys should be used only at the lower temperatures for long time applications. Likewise, Ta-10W displayed similar grain growth related instabilities. Otherwise the alloys investigated were generally acceptable for high temperature application from the standpoint of structural stability.
3. The magnitude of the aging response tended to be greatest for gas tungsten arc welds and least for base metal specimens.
4. An important difference in bend test fracture mode was noted for aged T-111 and T-222 bend specimens compared with columbium-base alloys. Even though shifts in transition behavior were noted, fractures were ductile intergranular separations which did not propagate from the weld metal into the base metal. Columbium-base alloys tended to display unarrested cracking and a classic, abrupt transition from ductile to brittle cleavage behavior. Hence, the bend transition temperature represents a design limit for columbium alloys but not for the tantalum alloys.

5. T-111, T-222 and FS-85 displayed similar responses to aging. These were detected only in measurements of the bend transition temperature, not being observed in tensile tests at room temperature or elevated temperatures. The fact no evidence of a response was seen in high temperature tensile tests demonstrated that the thermal stability is excellent from a design standpoint. Of these, FS-85 alone would be limited but only in an unusual situation requiring periodic cycling from the aging temperatures to below the bend transition temperature.

V. REFERENCES

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APPENDIX A - PROGRAM DATA COMPILATION

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
A1	Key for Presentation of Bend Test Data	54
A2	Tensile Yield Strength of T-111 as a Function of Aging Parameters	55
A3	Tensile Elongation of T-111 as a Function of Aging Parameters	56
A4	Bend Test Results for T-111 Aged 100 and 1000 Hours at 1500° F	57
A5	Bend Test Results for T-111 Aged 5000 and 10,000 Hours at 1500° F	58
A6	Bend Test Results for T-111 Aged 100 and 1000 Hours at 1800° F	59
A7	Bend Test Results for T-111 Aged 5000 and 10,000 Hours at 1800° F	60
A8	Bend Test Results for T-111 Aged 100 and 1000 Hours at 2100° F	61
A9	Bend Test Results for T-111 Aged 5000 and 10,000 Hours at 2100° F	62
A10	Bend Test Results for T-111 Aged 100 and 1000 Hours at 2400° F	63
A11	Bend Test Results for T-111 Aged 5000 and 10,000 Hours at 2400° F	64
A12	Hardness Traverses for T-111 GTA Sheet Welds. Thermal History as Indicated.	65
A13	Tensile Yield Strength of T-222 as a Function of Aging Parameters	66
A14	Tensile Elongation of T-222 as a Function of Aging Parameters	67
A15	Bend Test Results for T-222 Aged 100 and 1000 Hours at 1500° F	68
A16	Bend Test Results for T-222 Aged 5000 and 10,000 Hours at 1500° F	69
A17	Bend Test Results for T-222 Aged 100 and 1000 Hours at 1800° F	70
A18	Bend Test Results for T-222 Aged 5000 and 10,000 Hours at 1800° F	71
A19	Bend Test Results for T-222 Aged 100 and 1000 Hours at 2100° F	72
A20	Bend Test Results for T-222 Aged 5000 and 10,000 Hours at 2100° F	73

APPENDIX A - PROGRAM DATA COMPILATION (Continued)

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
A21	Bend Test Results for T-222 Aged 100 and 1000 Hours at 2400° F	74
A22	Bend Test Results for T-222 Aged 5000 and 10,000 Hours at 2400° F	75
A23	Hardness Traverses for T-222 GTA Sheet Welds. Thermal History as Indicated.	76
A24	Tensile Yield Strength of FS-85 as a Function of Aging Parameters	77
A25	Tensile Elongation of FS-85 as a Function of Aging Parameters	78
A26	Bend Test Results for FS-85 Aged 100 and 1000 Hours at 1500° F	79
A27	Bend Test Results for FS-85 Aged 5000 and 10,000 Hours at 1500° F	80
A28	Bend Test Results for FS-85 Aged 100 and 1000 Hours at 1800° F	81
A29	Bend Test Results for FS-85 Aged 5000 and 10,000 Hours at 1800° F	82
A30	Bend Test Results for FS-85 Aged 100 and 1000 Hours at 2100° F	83
A31	Bend Test Results for FS-85 Aged 5000 and 10,000 Hours at 2100° F	84
A32	Bend Test Results for FS-85 Aged 100 and 1000 Hours at 2400° F	85
A33	Bend Test Results for FS-85 Aged 5000 and 10,000 Hours at 2400° F	86
A34	Hardness Traverses for FS-85 GTA Sheet Welds. Thermal History as Indicated.	87
A35	Ultimate Tensile Strength of B-66 as a Function of Aging Parameters	88
A36	Tensile Yield Strength of B-66 as a Function of Aging Parameters	89
A37	Tensile Elongation of B-66 as a Function of Aging Parameters	90
A38	Bend Test Results for B-66 Aged 100 and 1000 Hours at 1500° F	91
A39	Bend Test Results for B-66 Aged 5000 and 10,000 Hours at 1500° F	92
A40	Bend Test Results for B-66 Aged 100 and 1000 Hours at 1800° F	93

APPENDIX A - PROGRAM DATA COMPILATION (Continued)

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
A41	Bend Test Results for B-66 Aged 5000 and 10,000 Hours at 1800° F	94
A42	Bend Test Results for B-66 Aged 100 and 1000 Hours at 2100° F	95
A43	Bend Test Results for B-66 Aged 5000 and 10,000 Hours at 2100° F	96
A44	Bend Test Results for B-66 Aged 100 and 1000 Hours at 2400° F	97
A45	Bend Test Results for B-66 Aged 5000 and 10,000 Hours at 2400° F	98
A46	Hardness Traverses for B-66 GTA Sheet Welds. Thermal History as Indicated.	99
A47	Microstructures of B-66 GTA Weld Specimens. Thermal History as Indicated.	100
A48	Tensile Yield Strength of D-43 as a Function of Aging Parameters	101
A49	Tensile Elongation of D-43 as a Function of Aging Parameters	102
A50	Bend Ductile-Brittle Transition Temperature of D-43 as a Function of Aging Parameters	103
A51	Bend Test Results for D-43 Aged 100 and 1000 Hours at 1500° F	104
A52	Bend Test Results for D-43 Aged 5000 and 10,000 Hours at 1500° F	105
A53	Bend Test Results for D-43 Aged 100 and 1000 Hours at 1800° F	106
A54	Bend Test Results for D-43 Aged 5000 and 10,000 Hours at 1800° F	107
A55	Bend Test Results for D-43 Aged 100 and 1000 Hours at 2100° F	108
A56	Bend Test Results for D-43 Aged 5000 and 10,000 Hours at 2100° F	109
A57	Bend Test Results for D-43 Aged 100 and 1000 Hours at 2400° F	110
A58	Bend Test Results for D-43 Aged 5000 and 10,000 Hours at 2400° F	111
A59	Hardness Traverses for D-43 GTA Sheet Welds. Thermal History as Indicated.	112

APPENDIX A - PROGRAM DATA COMPIRATION (Continued)

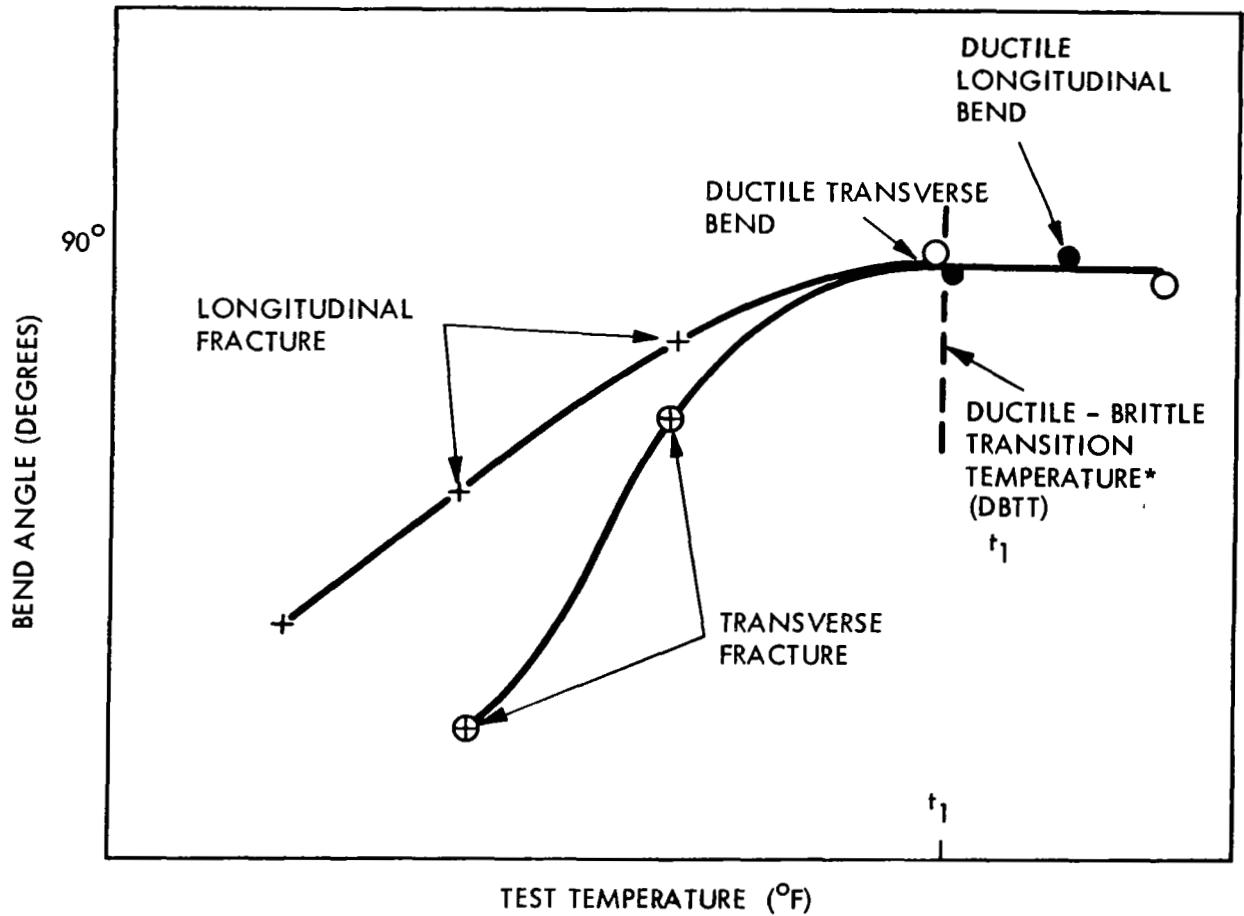
<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
A60	Tensile Yield Strength of Cb-752 as a Function of Aging Parameters	113
A61	Tensile Elongation of Cb-752 as a Function of Aging Parameters	114
A62	Bend Ductile-Brittle Transition Temperature of Cb-752 as a Function of Aging Parameters	115
A63	Bend Test Results for Cb-752 Aged 100 and 1000 Hours at 1500° F	116
A64	Bend Test Results for Cb-752 Aged 100 and 1000 Hours at 1800° F	117
A65	Bend Test Results for Cb-752 Aged 100 and 1000 Hours at 2100° F	118
A66	Bend Test Results for Cb-752 Aged 100 and 1000 Hours at 2400° F	119
A67	Hardness Traverses for Cb-752 GTA Sheet Welds. Thermal History as Indicated.	120
A68	Microstructures of Cb-752 GTA Weld Specimens. Thermal History as Indicated.	121
A69	Ultimate Tensile Strength of C-129Y as a Function of Aging Parameters	122
A70	Tensile Yield Strength of C-129Y as a Function of Aging Parameters	123
A71	Tensile Elongation of C-129Y as a Function of Aging Parameters	124
A72	Bend Ductile-Brittle Transition Temperature of C-129Y as a Function of Aging Parameters	125
A73	Bend Test Results for C-129Y Aged 100 and 1000 Hours at 1500° F	126
A74	Bend Test Results for C-129Y Aged 100 and 1000 Hours at 1800° F	127
A75	Bend Test Results for C-129Y Aged 100 and 1000 Hours at 2100° F	128
A76	Bend Test Results for C-129Y Aged 100 and 1000 Hours at 2400° F	129
A77	Hardness Traverses for C-129Y GTA Sheet Welds. Thermal History as Indicated	130

APPENDIX A - PROGRAM DATA COMPILATION (Continued)

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
A78	Microstructures of C-129Y GTA Weld Specimens. Thermal History as Indicated.	131
A79	Ultimate Tensile Strength of Ta-10W as a Function of Aging Parameters	132
A80	Tensile Yield Strength of Ta-10W as a Function of Aging Parameters	133
A81	Tensile Elongation of Ta-10W as a Function of Aging Parameters	134
A82	Bend Ductile-Brittle Transition Temperature of Ta-10W as a Function of Aging Parameters	135
A83	Bend Test Results for Ta-10W Aged 100 and 1000 Hours at 1500° F	136
A84	Bend Test Results for Ta-10W Aged 100 and 1000 Hours at 1800° F	137
A85	Bend Test Results for Ta-10W Aged 100 and 1000 Hours at 2100° F	138
A86	Bend Test Results for Ta-10W Aged 100 and 1000 Hours at 2400° F	139
A87	Hardness Traverses for Ta-10W GTA Sheet Welds. Thermal History as Indicated.	140
A88	Microstructures of Ta-10W GTA Weld Specimens. Thermal History as Indicated.	141
A89	Ultimate Tensile Strength of SCb-291 as a Function of Aging Parameters	142
A90	Tensile Yield Strength of SCb-291 as a Function of Aging Parameters	143
A91	Tensile Elongation of SCb-291 as a Function of Aging Parameters	144
A92	Bend Ductile-Brittle Transition Temperature of SCb-291 as a Function of Aging Parameters	145
A93	Bend Test Results for SCb-291 Aged 100 and 1000 Hours at 1500° F	146
A94	Bend Test Results for SCb-291 Aged 100 and 1000 Hours at 1800° F	147

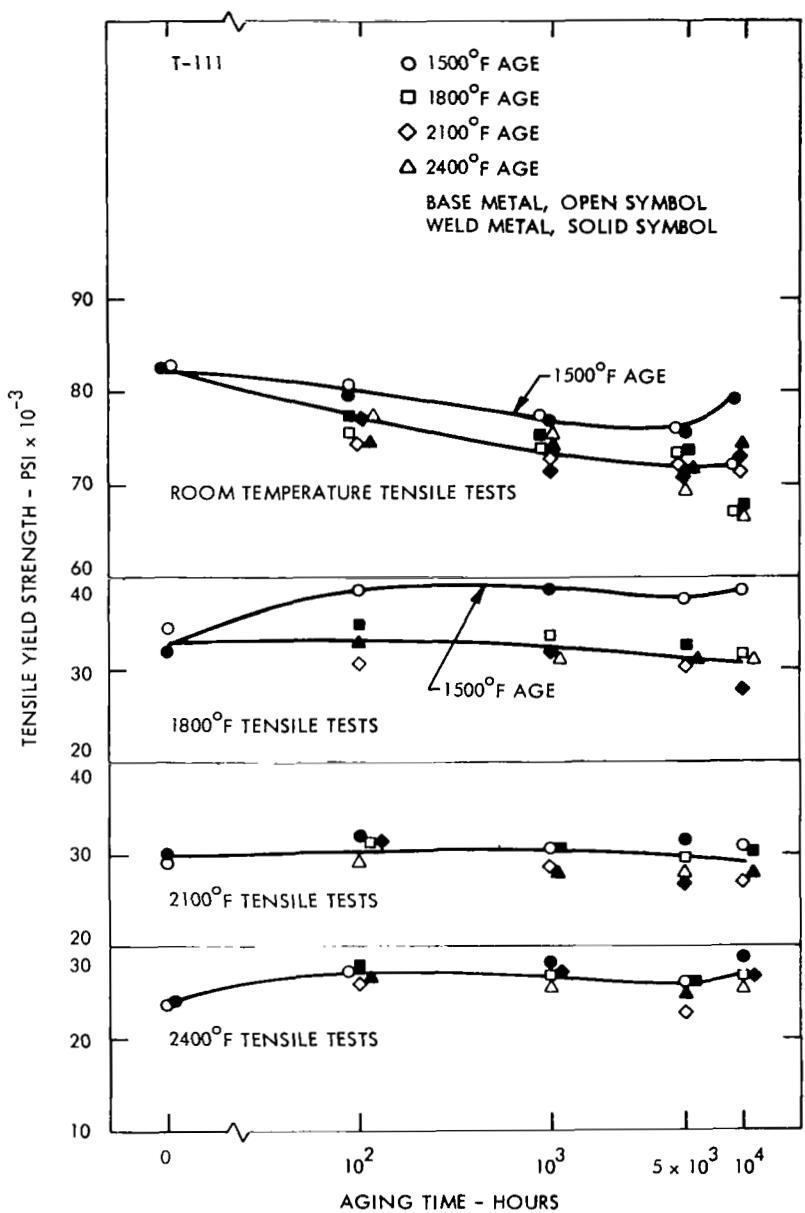
APPENDIX A - PROGRAM DATA COMPILATION (Continued)

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
A95	Bend Test Results for SCb-291 Aged 100 and 1000 Hours at 2100° F	148
A96	Bend Test Results for SCb-291 Aged 100 and 1000 Hours at 2400° F	149
A97	Hardness Traverses for SCb-291 GTA Sheet Welds. Thermal History as Indicated.	150
A98	Microstructures of SCb-291 GTA Weld Specimens. Thermal History as Indicated.	151



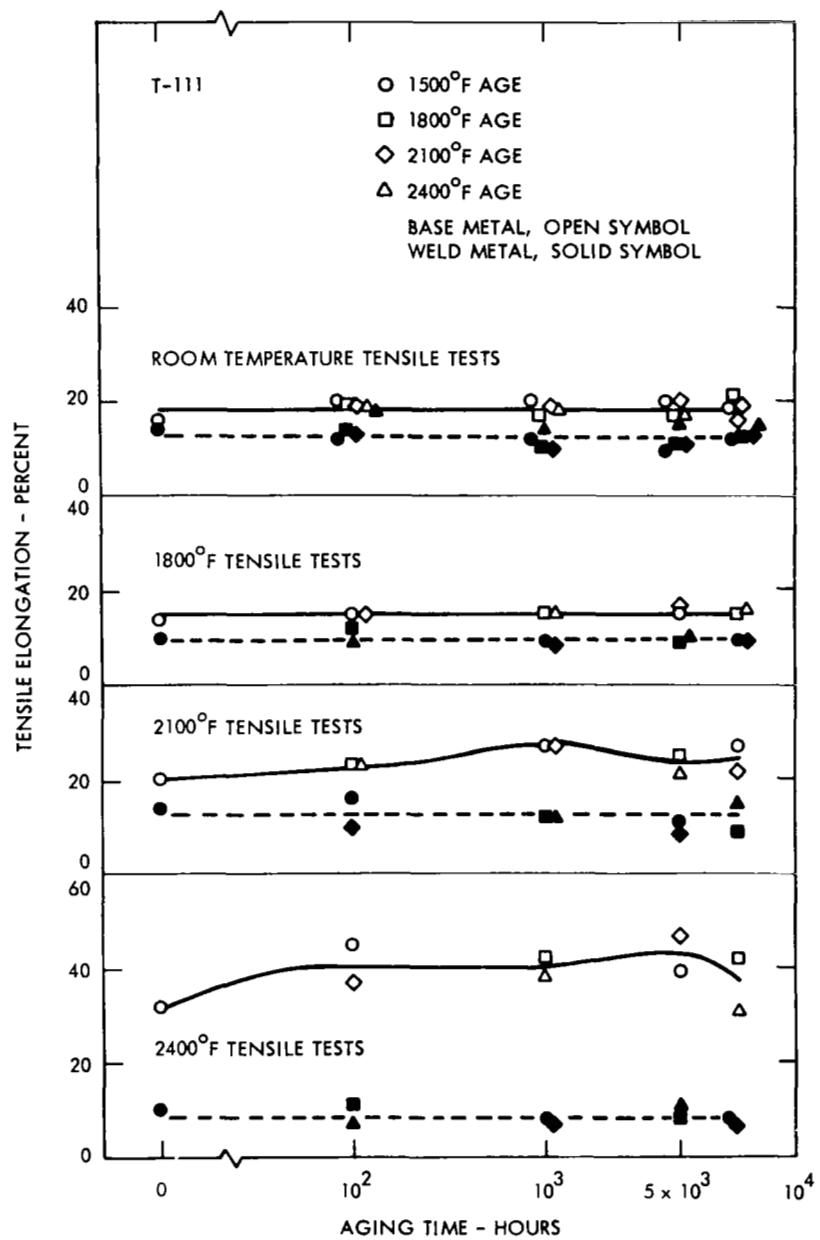
*TEMPERATURE OF LAST DUCTILE BEND AS CHECKED BY DYE PENETRANT EXAMINATION

FIGURE A1 - Key for Presentation of Bend Test Data



NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hr. at 2400°F Prior to Aging and Testing.

FIGURE A2 – Tensile Yield Strength of T-111 as a Function of Aging Parameters



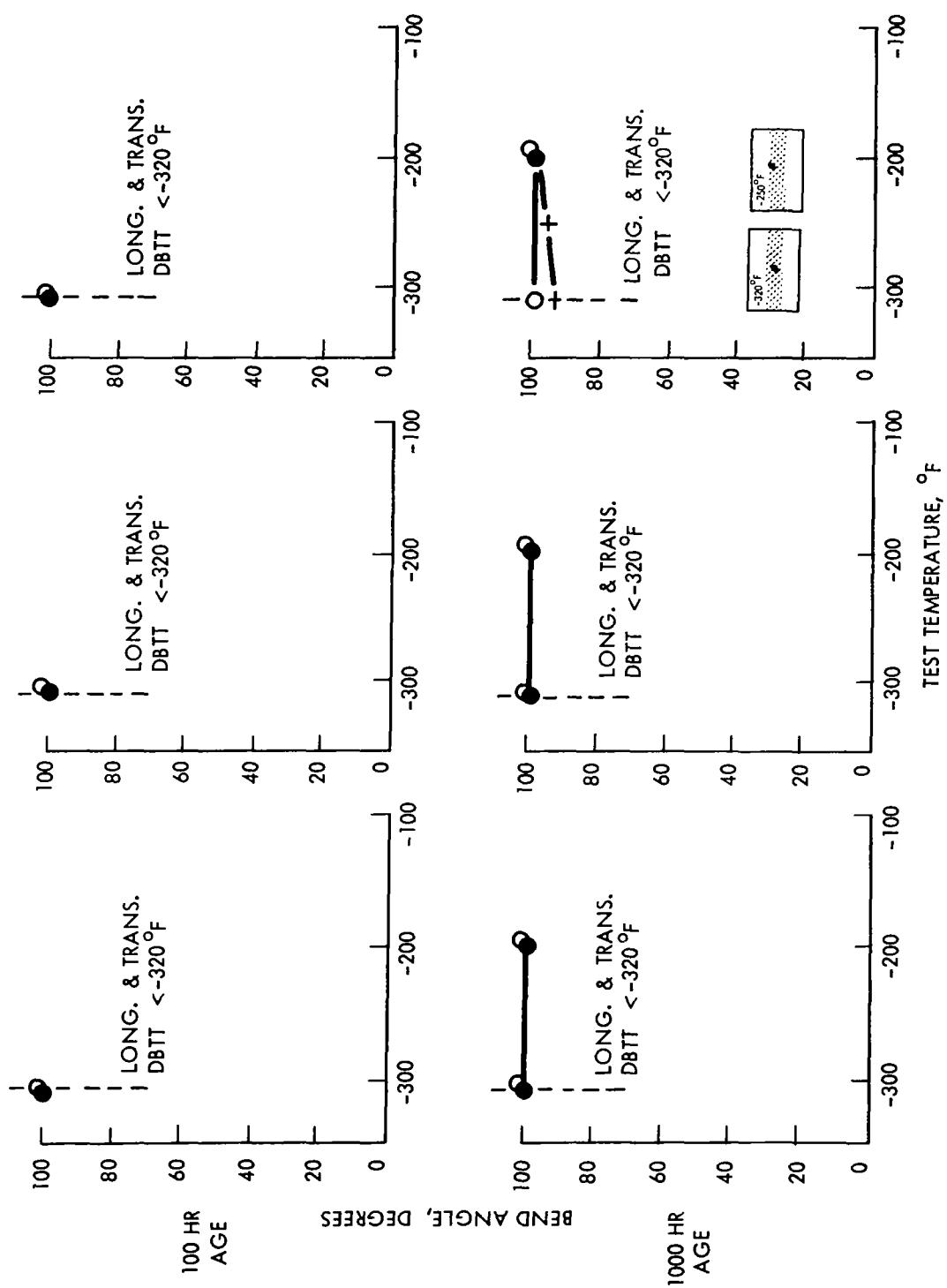
NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hr. at 2400°F Prior to Aging and Testing.

FIGURE A3 – Tensile Elongation of T-111 as a Function of Aging Parameters

GAS TUNGSTEN ARC WELDS

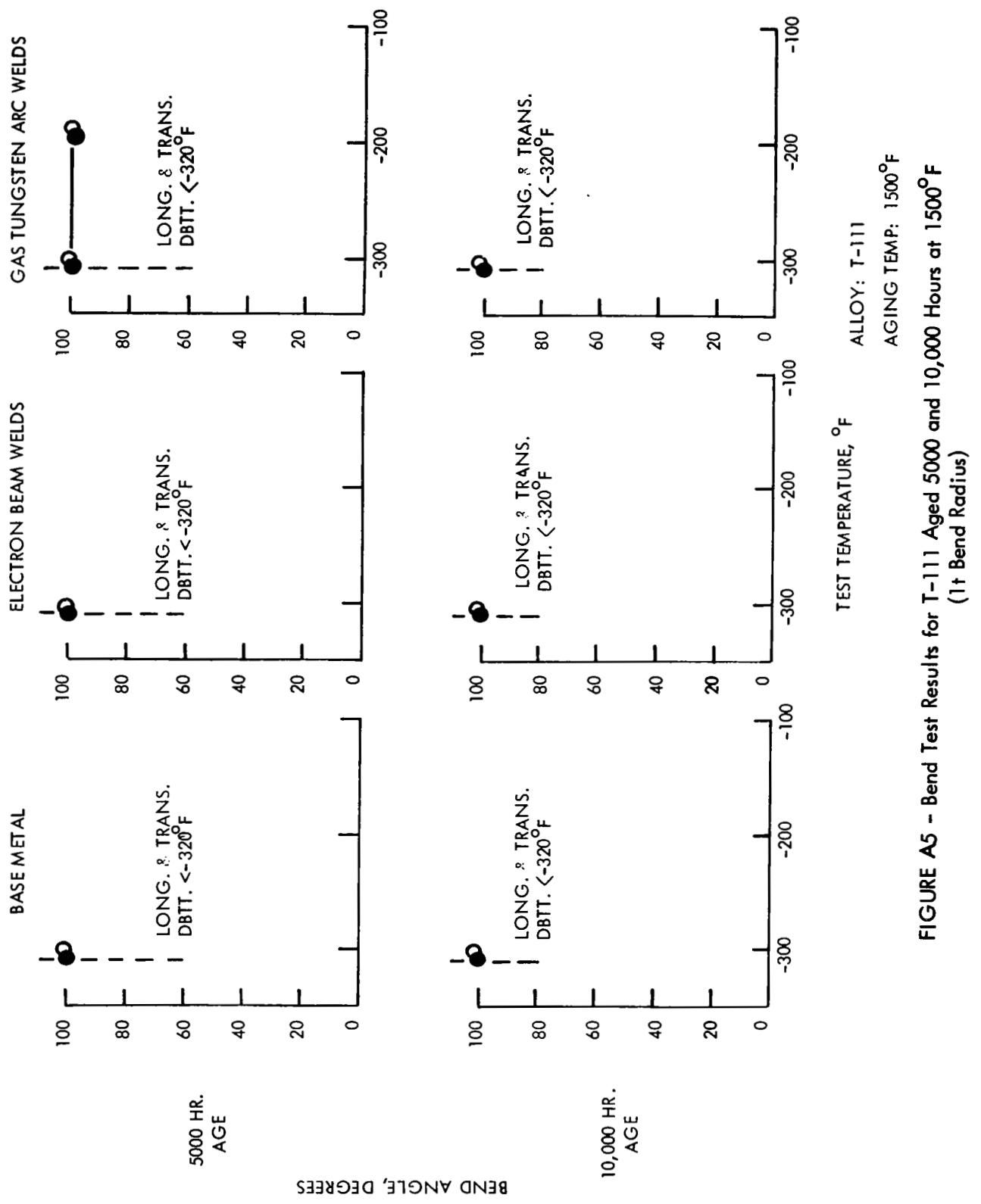
ELECTRON BEAM WELD

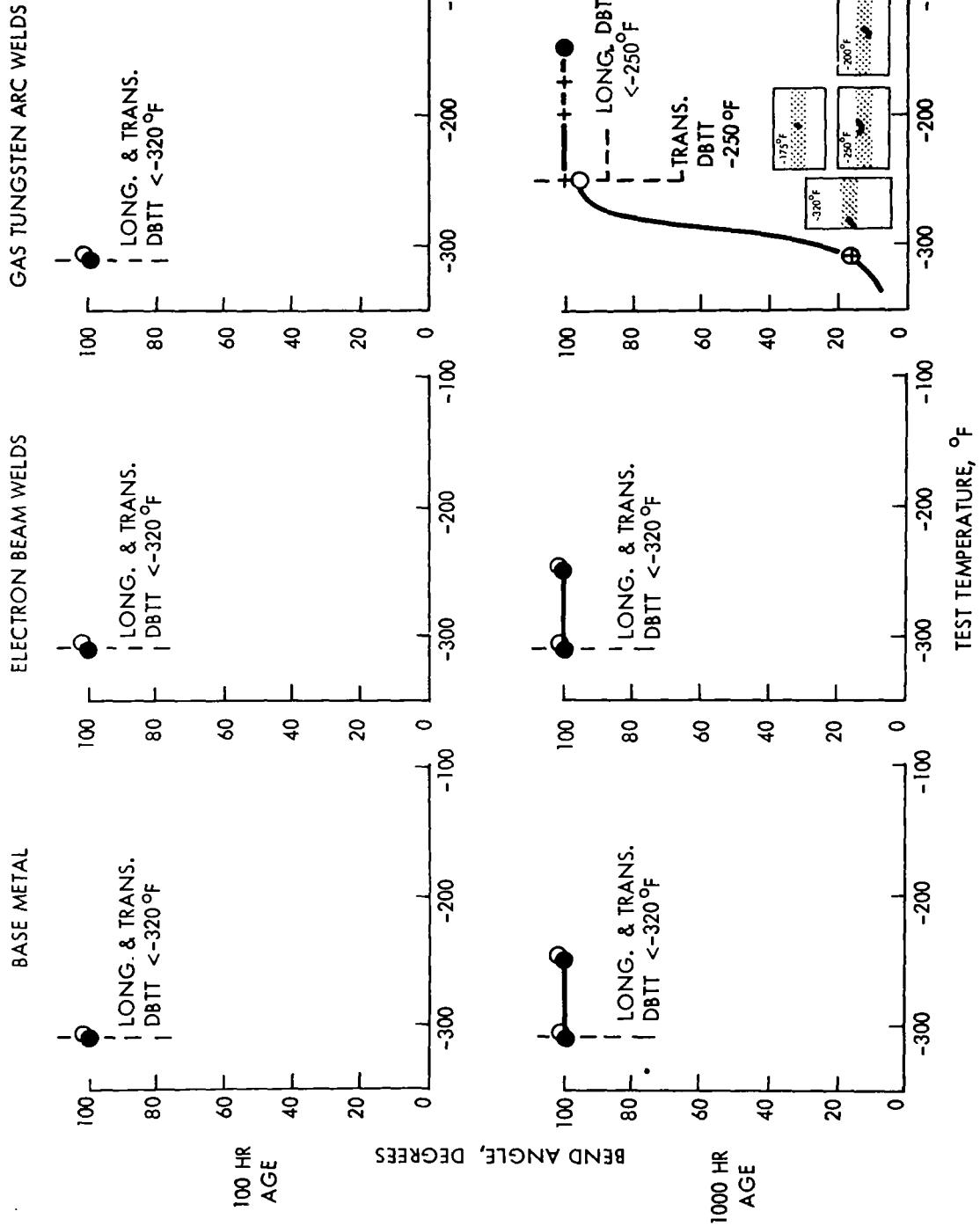
BASE METAL



ALLOY: T-111
AGING TEMP: 1500° F

**FIGURE A4 – Bend Test Results for T-111 Aged 100 and 1000 Hours at 1500° F
(1st Bend Radius)**





**FIGURE A6 - Bend Test Results for T-111 Aged 100 and 1000 Hours at 1800°F
(1† Bend Radius)**

ALLOY: T-111
AGING TEMP: 1800 °F

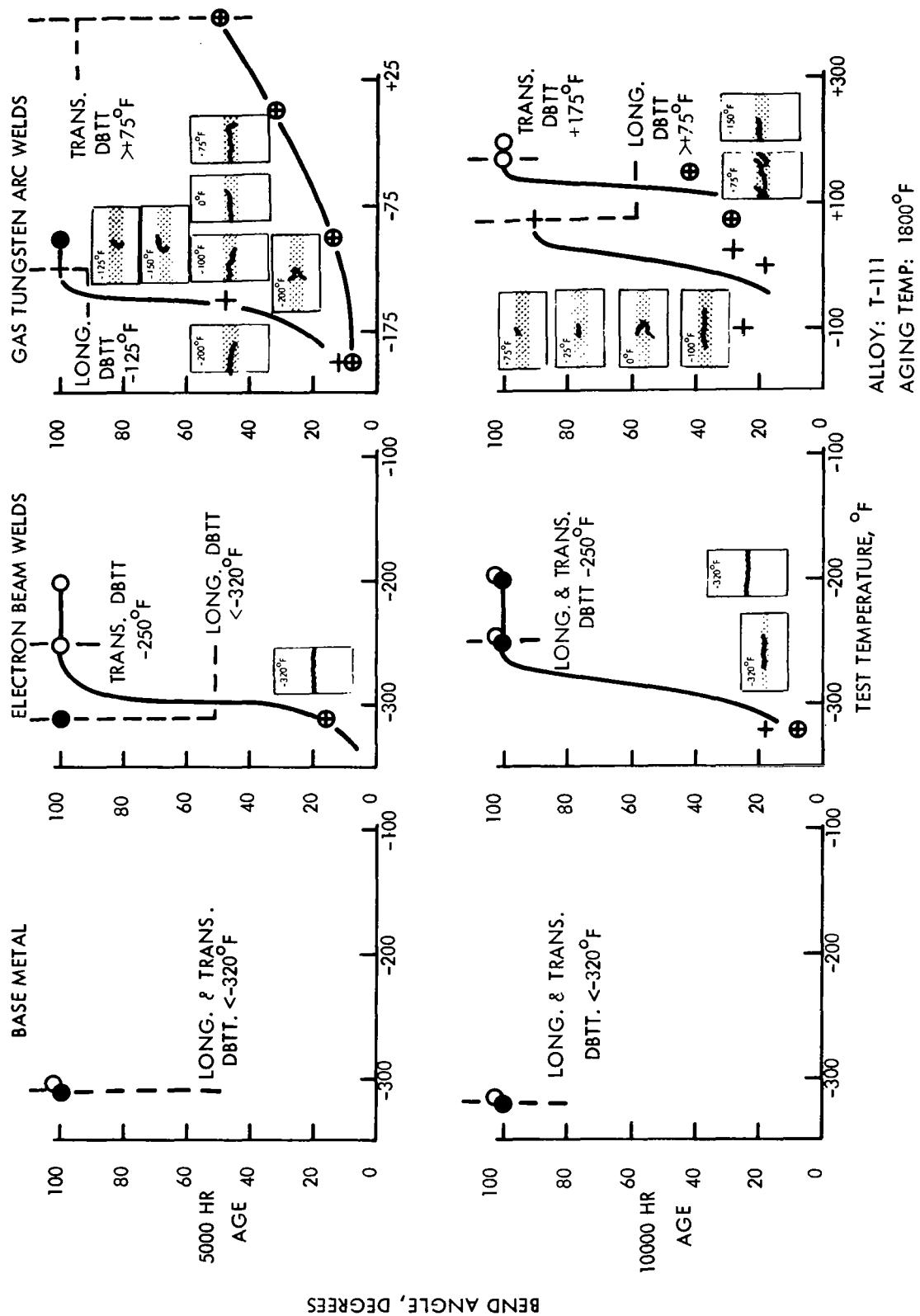
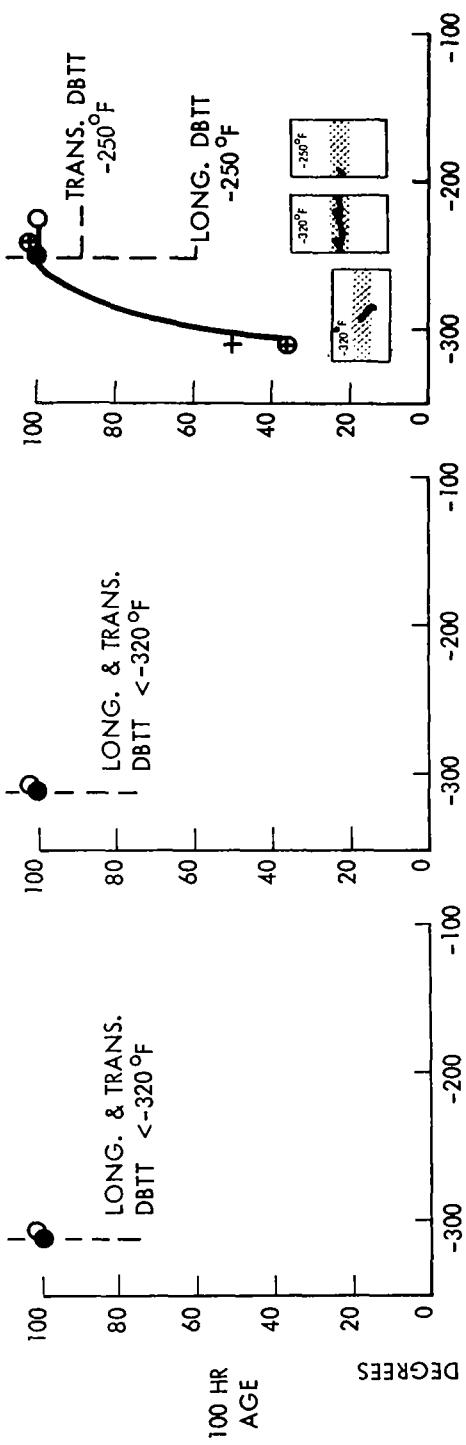


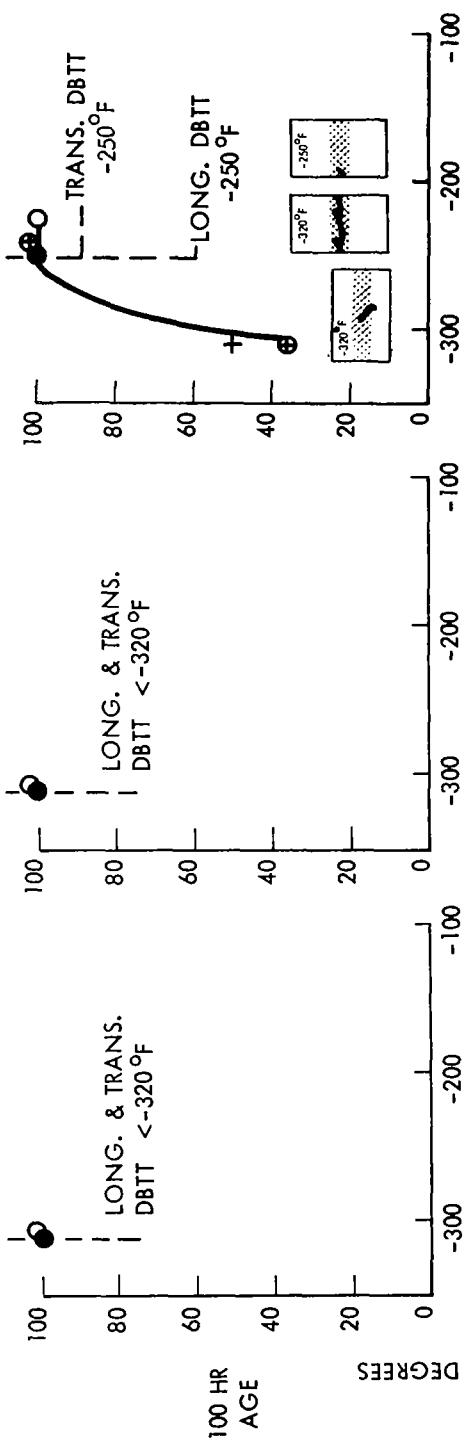
FIGURE A7 - Bend Test Results for T-111 Aged 5000 and 10,000 Hours at 1800°F
(1 = Round Bend, ...)

14 Round Panel

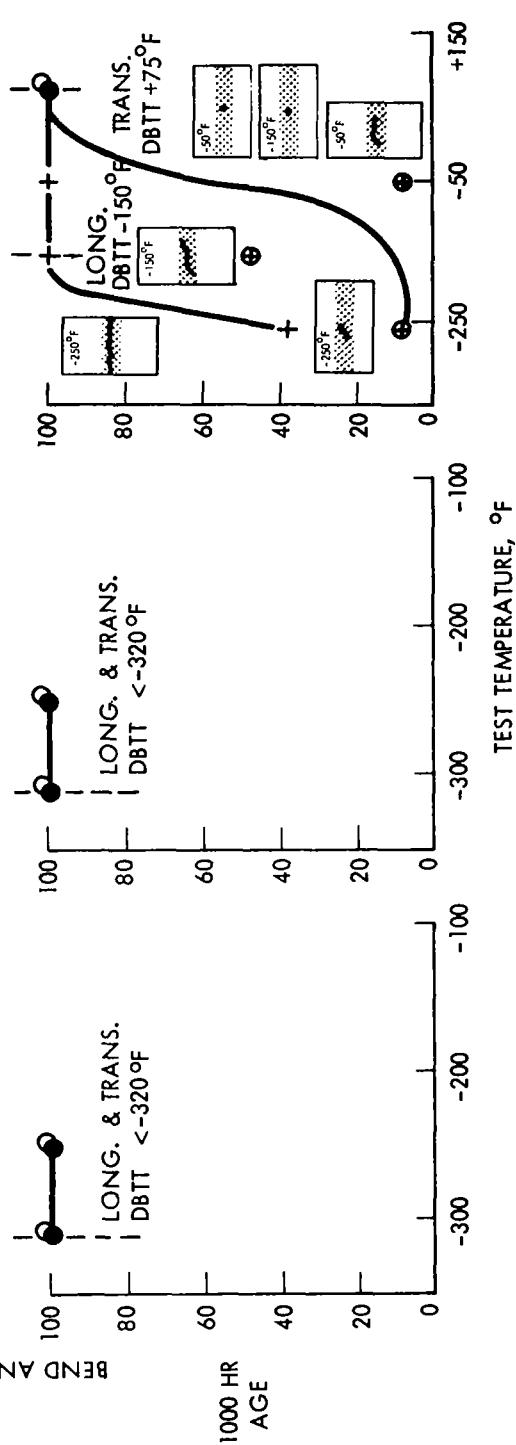
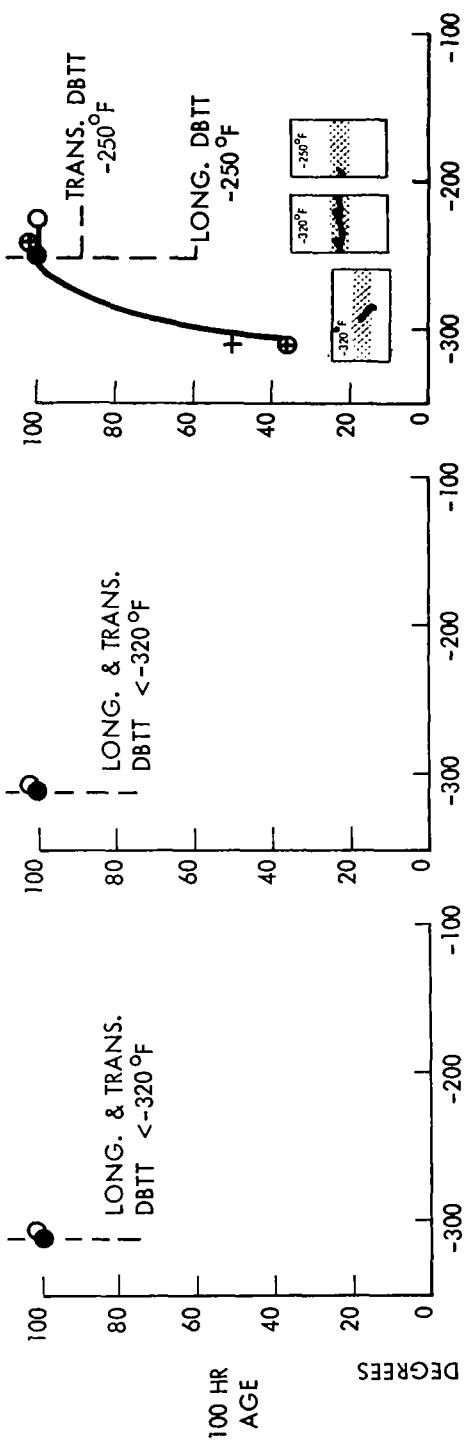
GAS TUNGSTEN ARC WELDS



ELECTRON BEAM WELDS

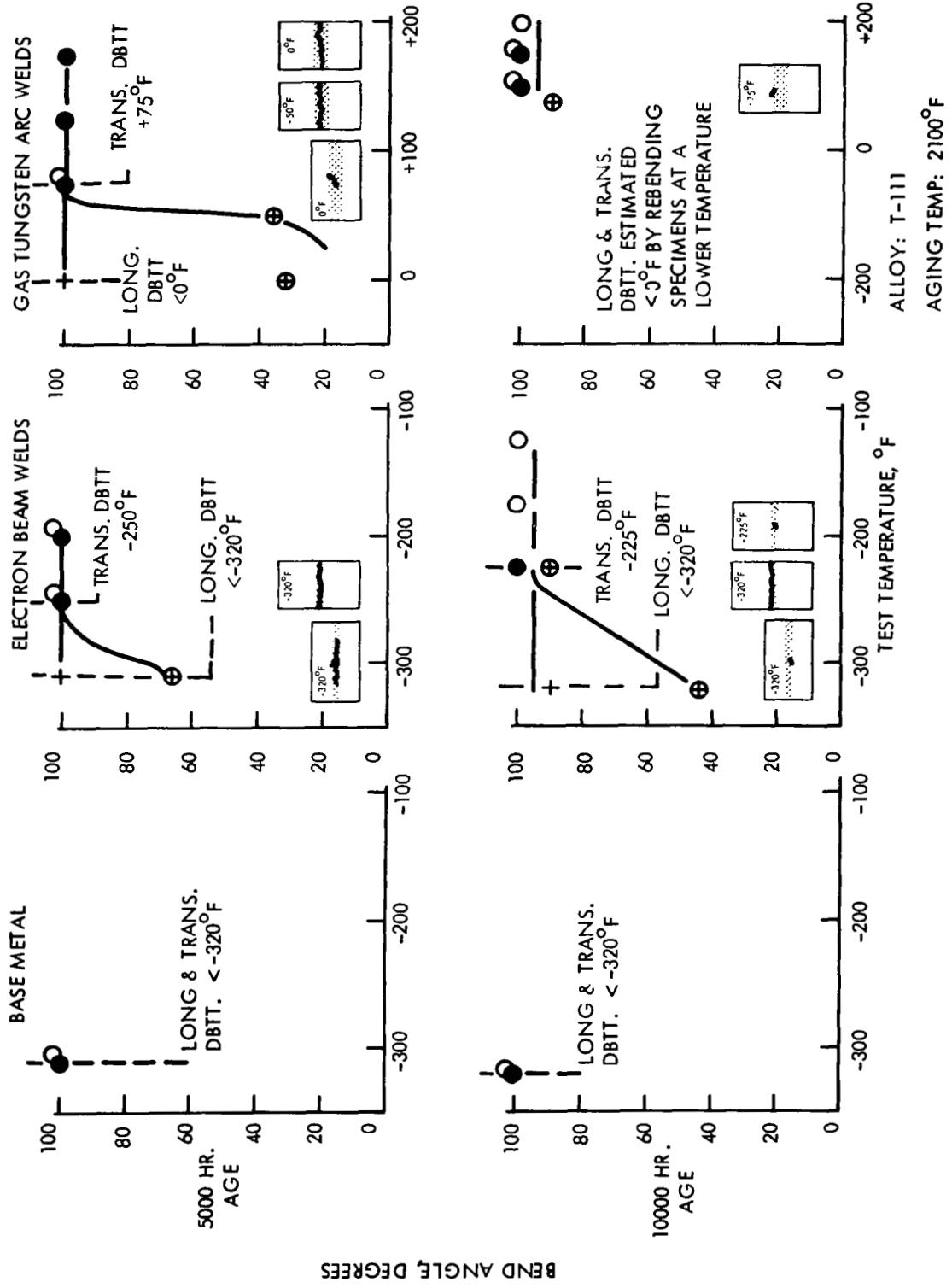


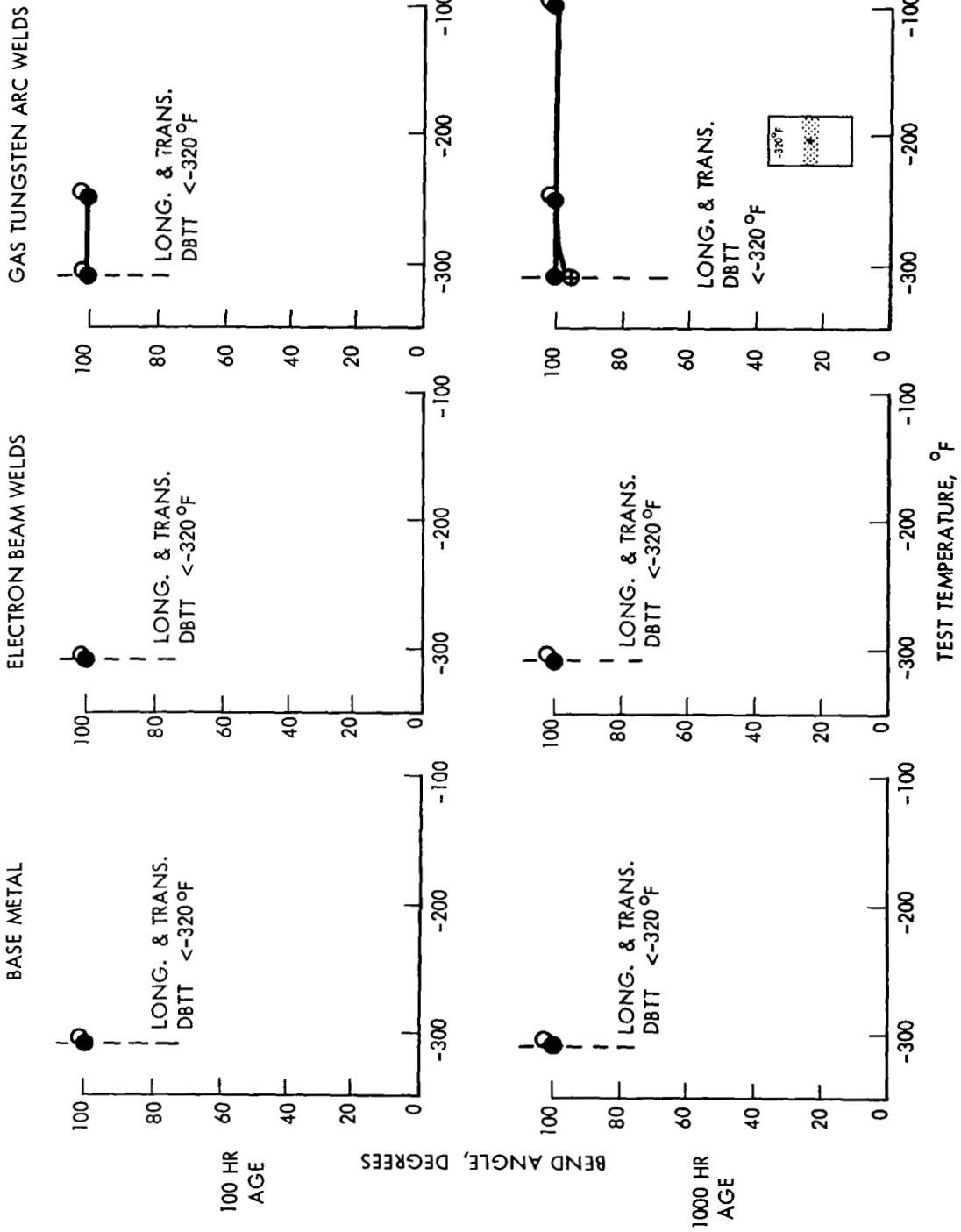
BASE METAL



ALLOY: T-111
AGING TEMP: 2100 °F

FIGURE A8 - Bend Test Results for T-111 Aged 100 and 1000 Hours at 2100°F
(1st Bend Radius)





**FIGURE A10 - Bend Test Results for T-111 Aged 100 and 1000 Hours at 2400° F
(1 ft Bend Radius)**

ALLOY: T-111
AGING TEMP: 2400 °F

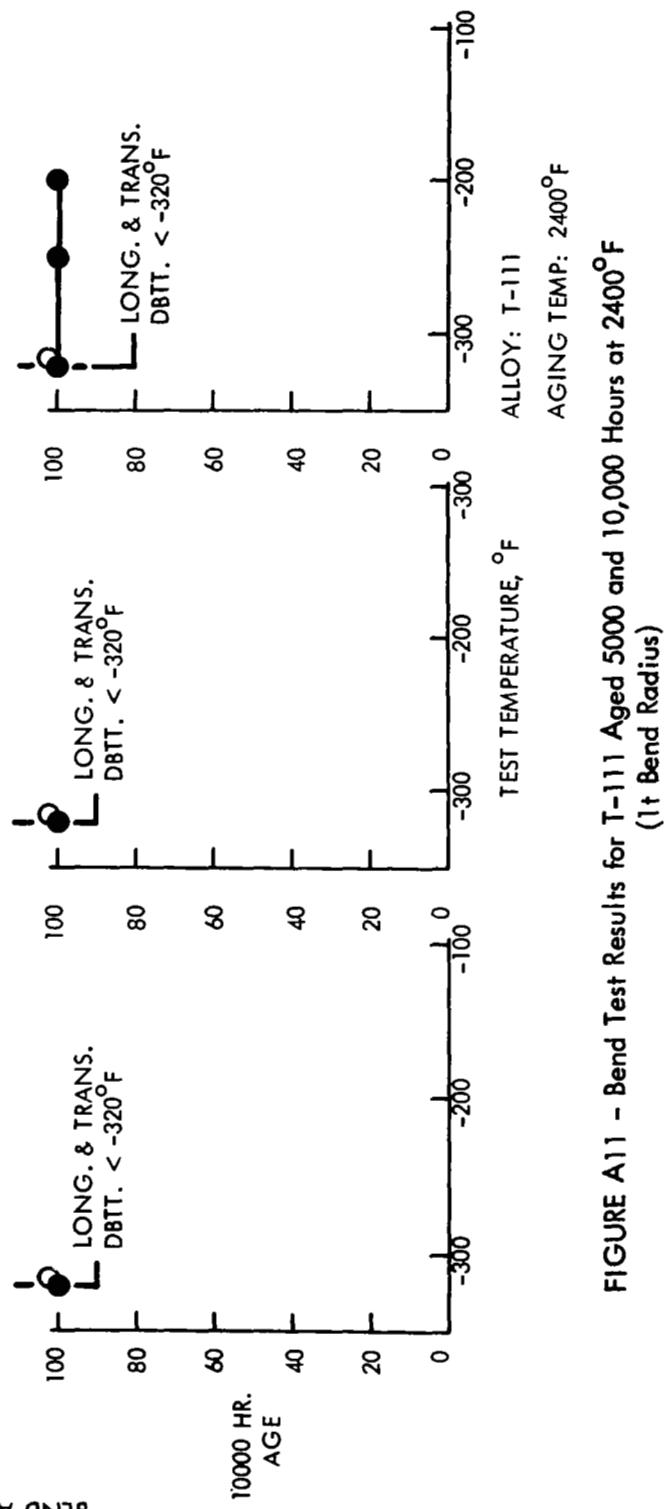
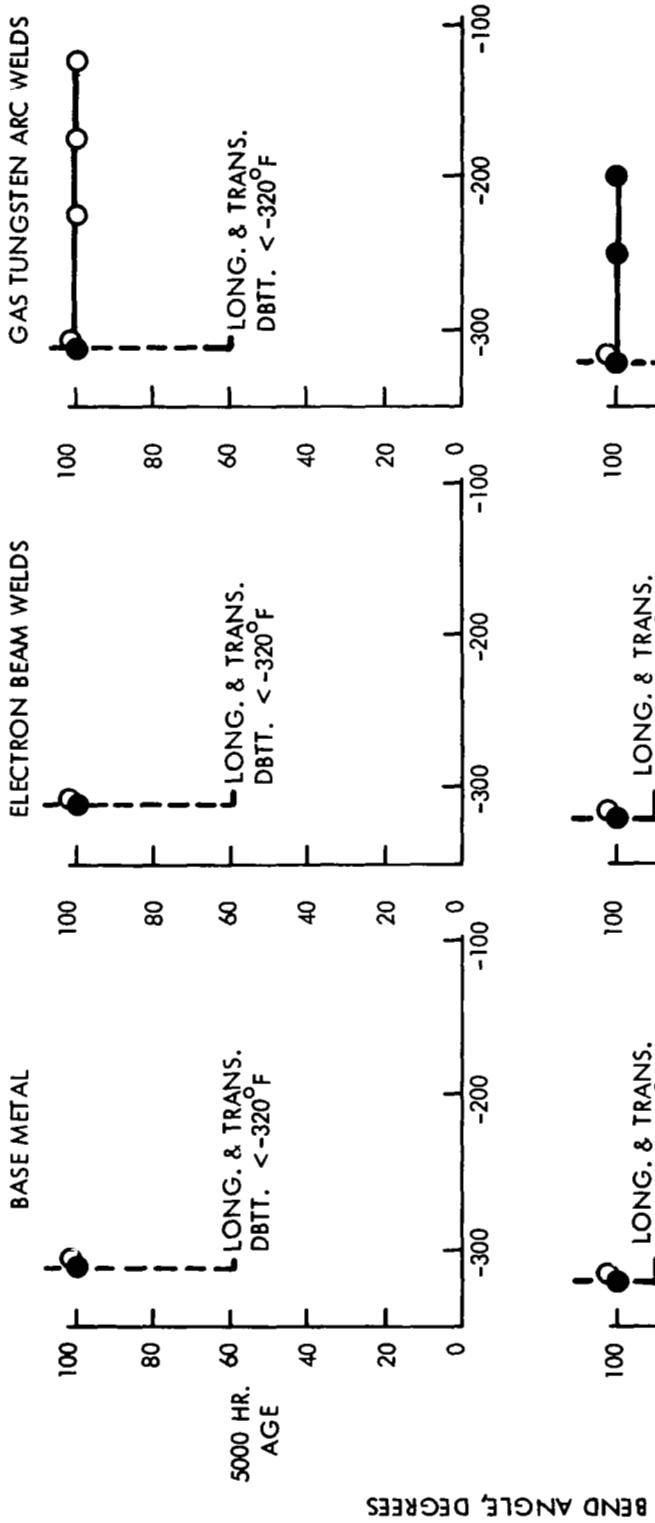
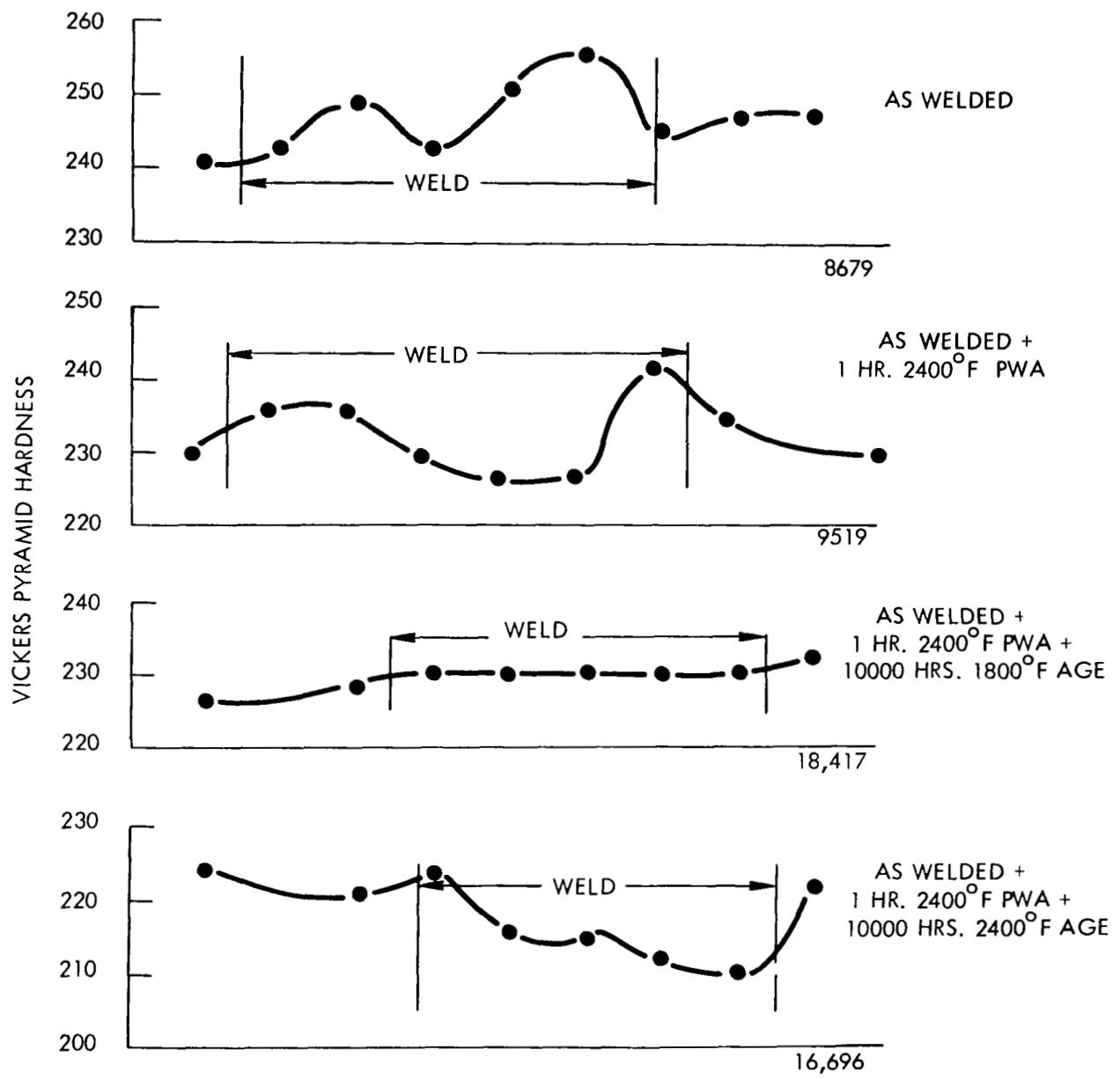
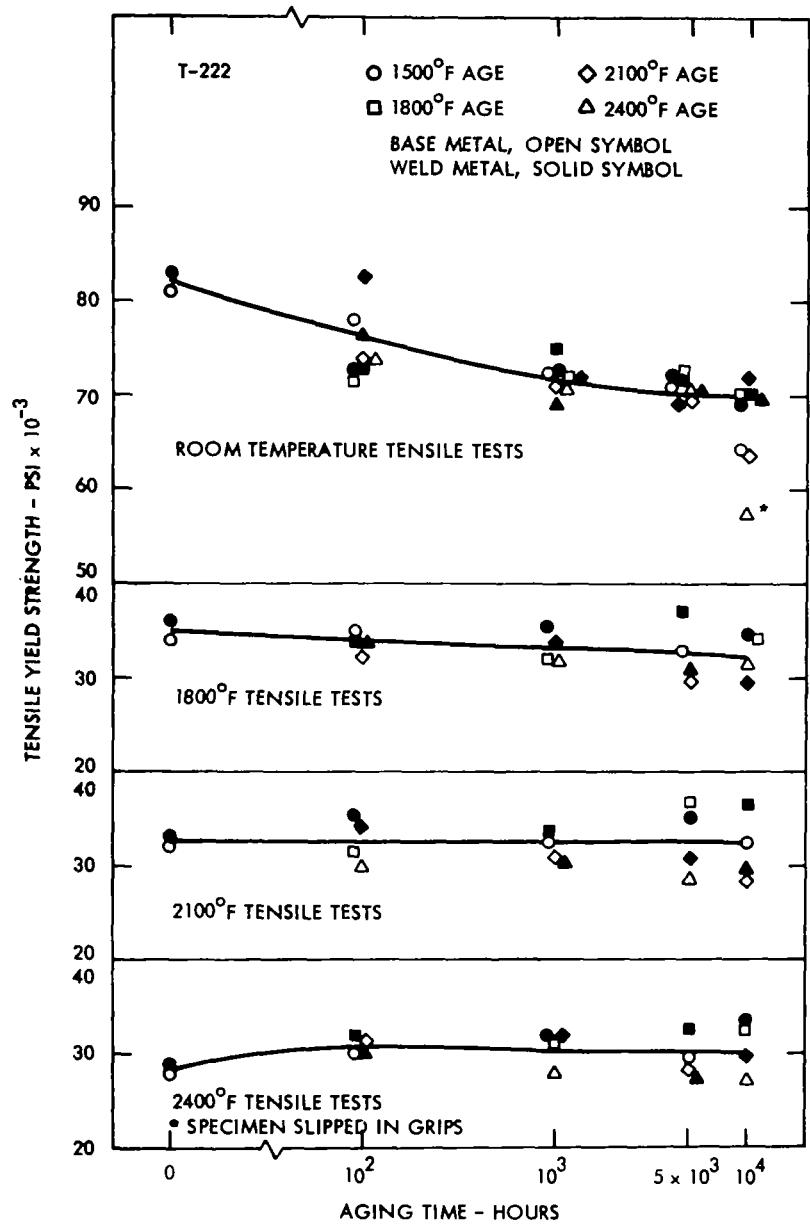


FIGURE A11 - Bend Test Results for T-111 Aged 5000 and 10,000 Hours at 2400°F (1" Bend Radius)

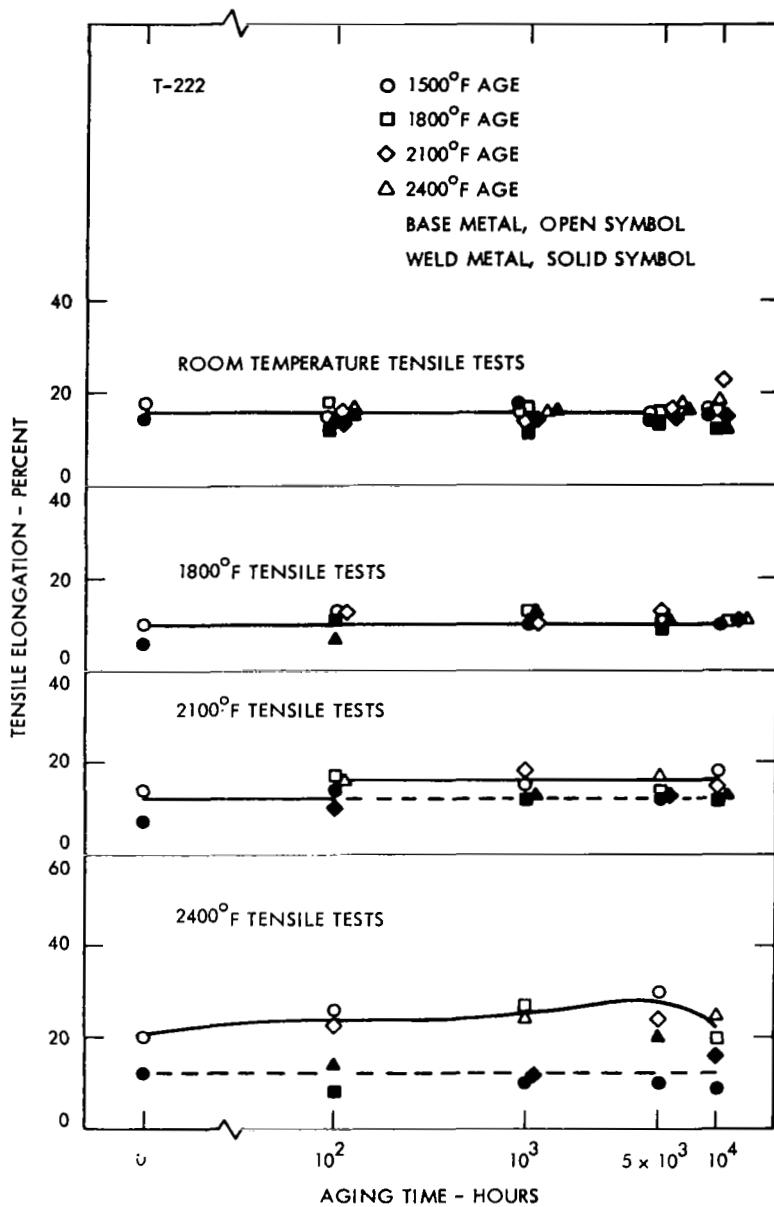


**FIGURE A12 - Hardness Traverses for T-111 GTA Sheet Welds.
Thermal History as Indicated. (10 Kg Load on
Vickers Hardness Tester)**



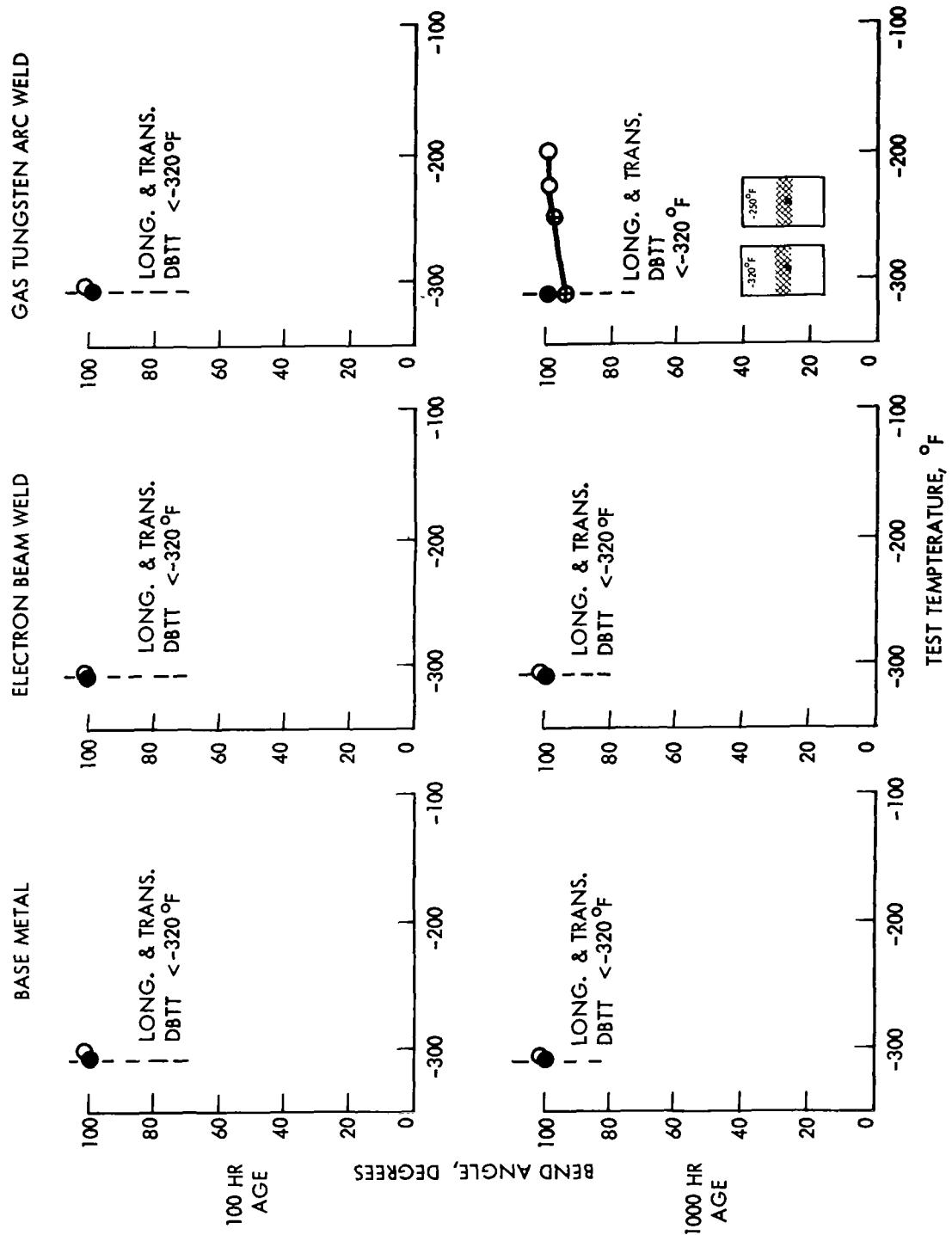
NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hour at 2400°F Prior to Aging and Testing.

FIGURE A13 – Tensile Yield Strength of T-222 as a Function of Aging Parameters



NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hour at 2400°F Prior to Aging and Testing.

FIGURE A14 - Tensile Elongation of T-222 as a Function of Aging Parameters



**FIGURE A15 – Bend Test Results for T-222 Aged 100 and 1000 Hours at 1500 °F
(1st Bend Radius)**

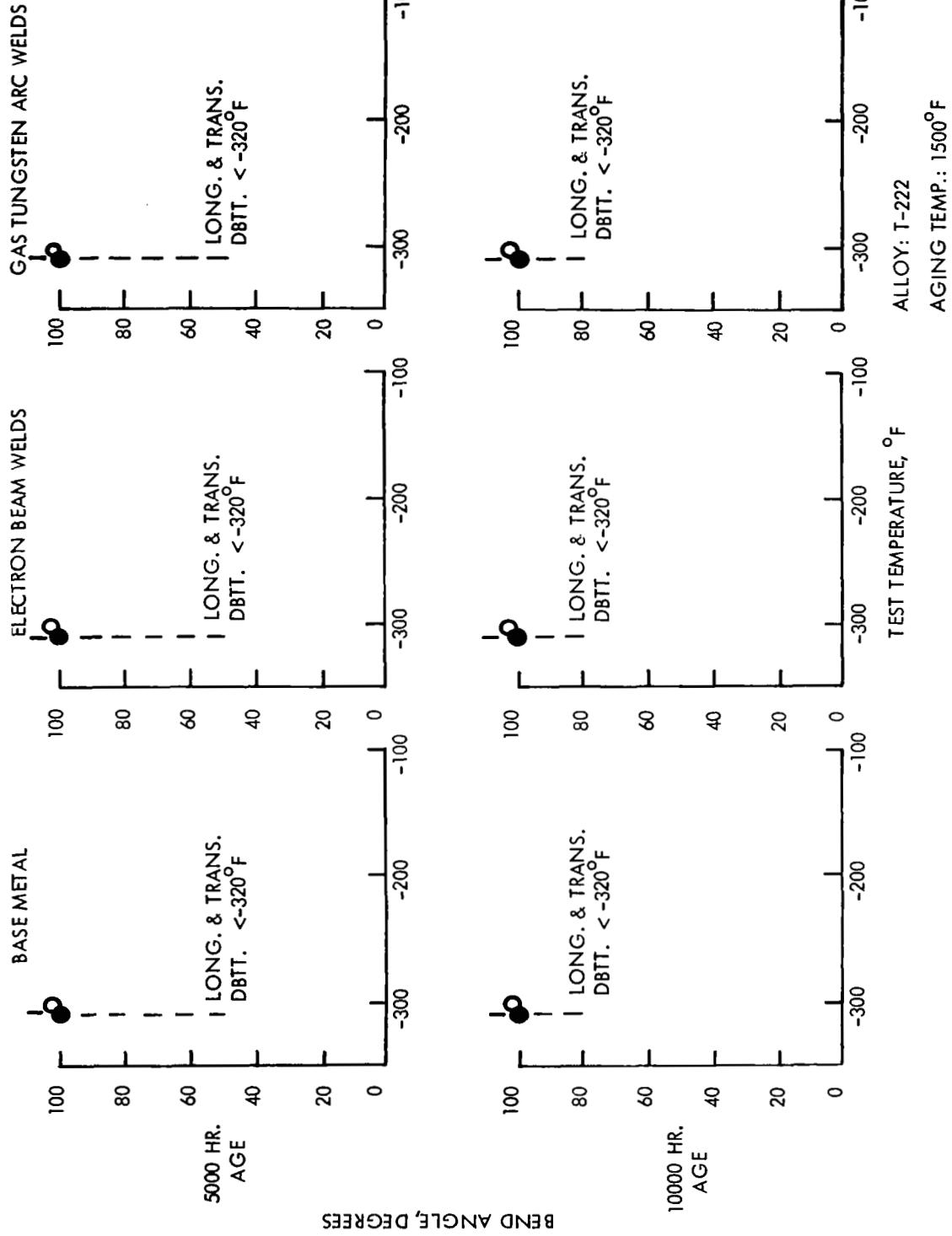


FIGURE A16 - Bend Test Results for T-222 Aged 5000 and 10,000 Hours at 1500°F
(1t Bend Radius)

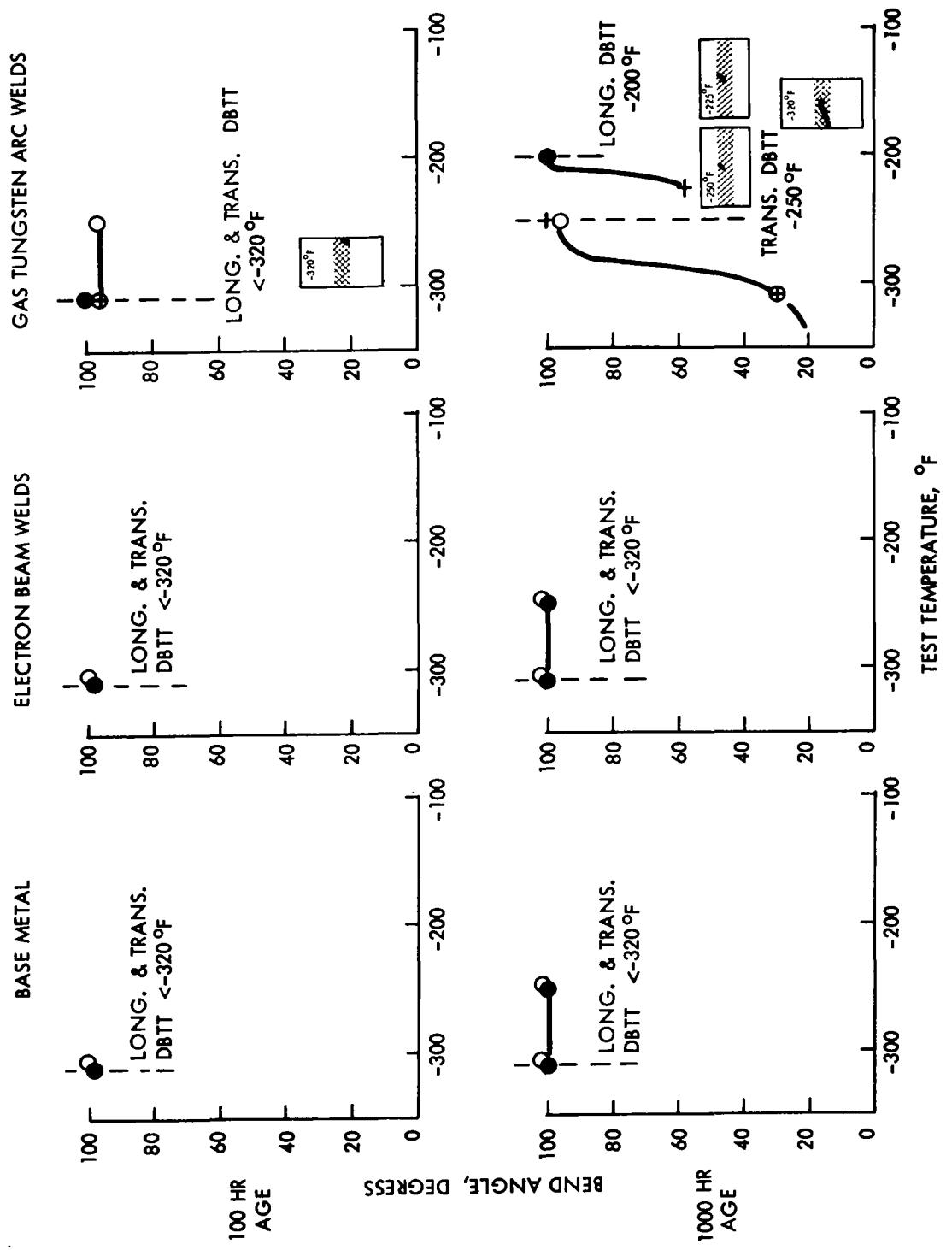
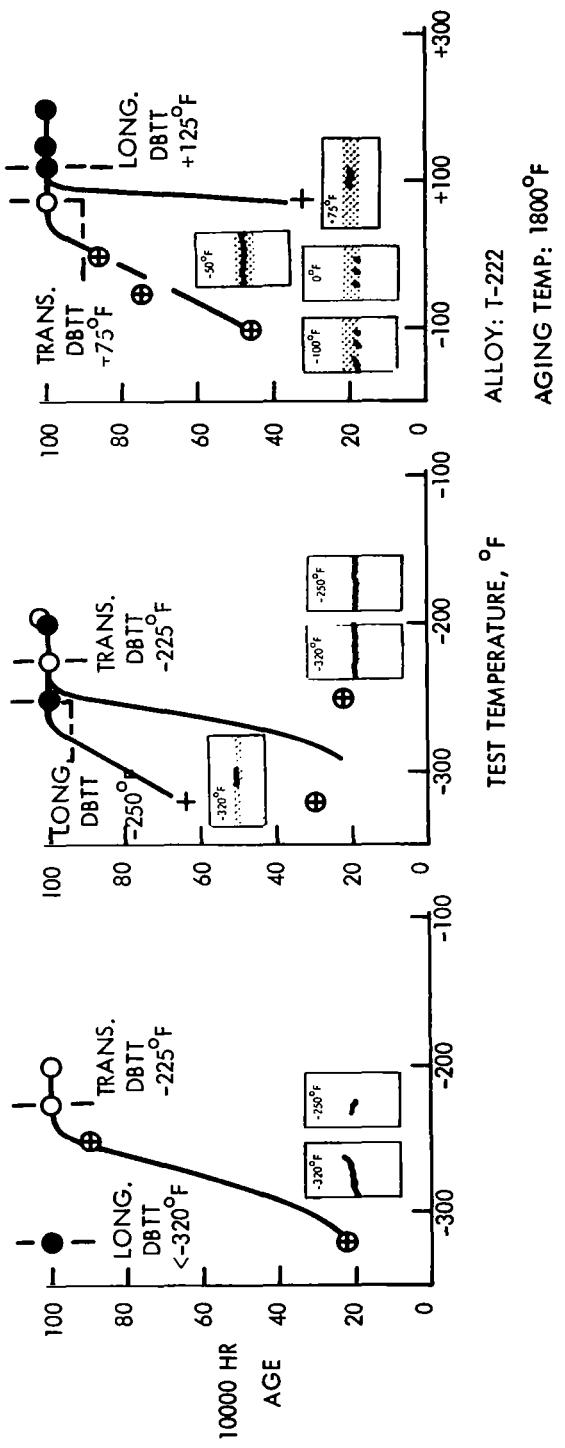
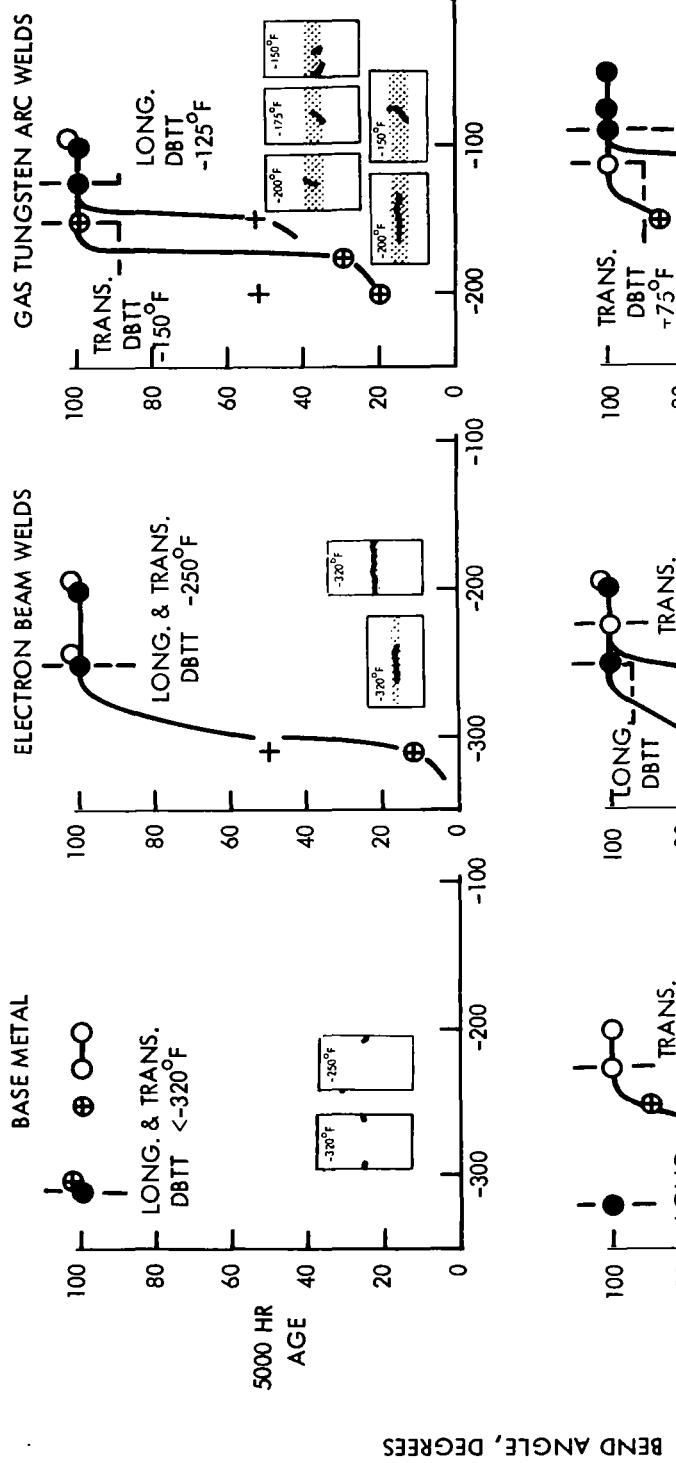
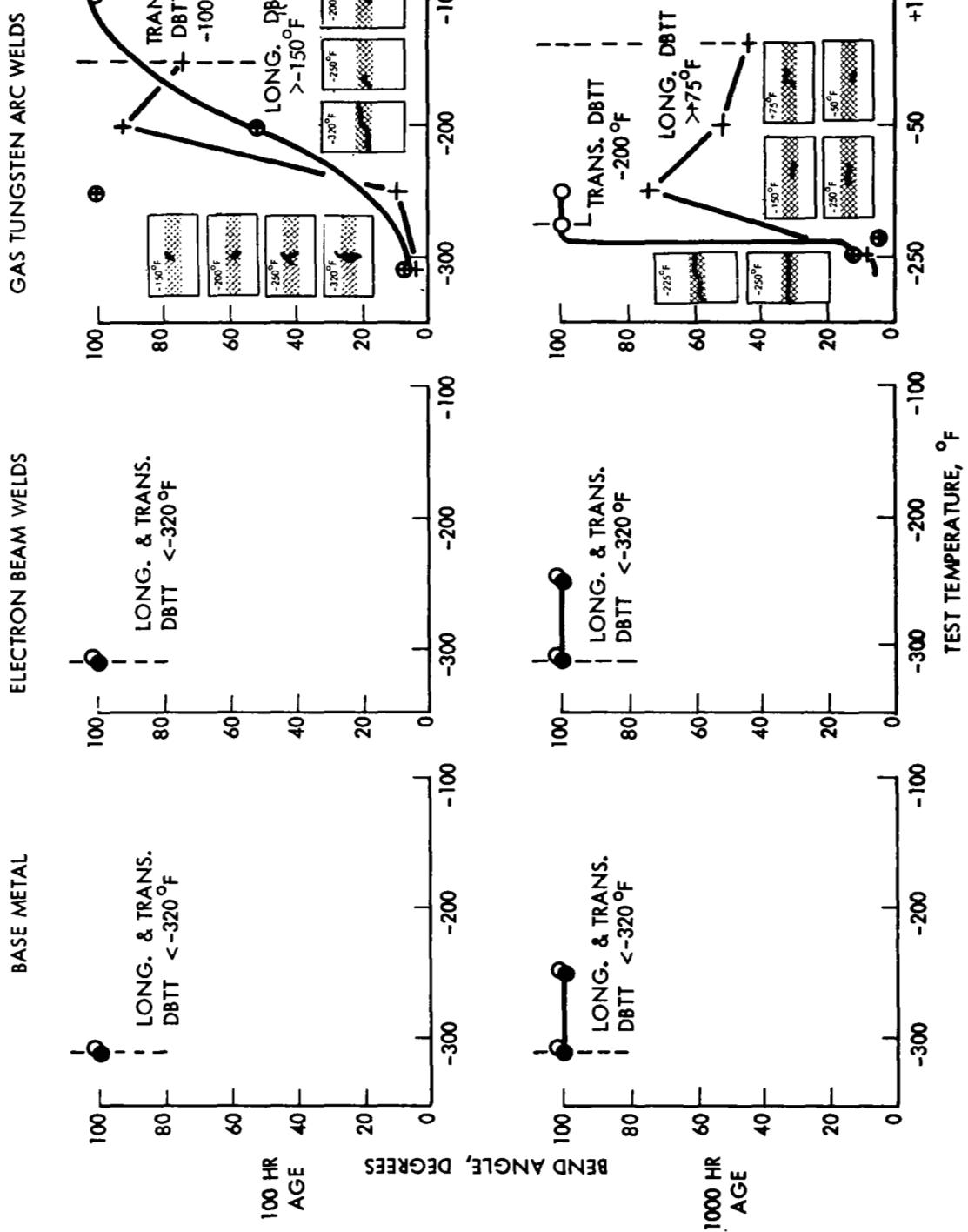


FIGURE A17 - Bend Test Results for T-222 Aged 100 and 1000 Hours at 1800°F (1t Bend Radius)



**FIGURE A18 - Bend Test Results for T-222 Aged 5000 and 10,000 Hours at 1800°F
(1 ft Bend Radius)**



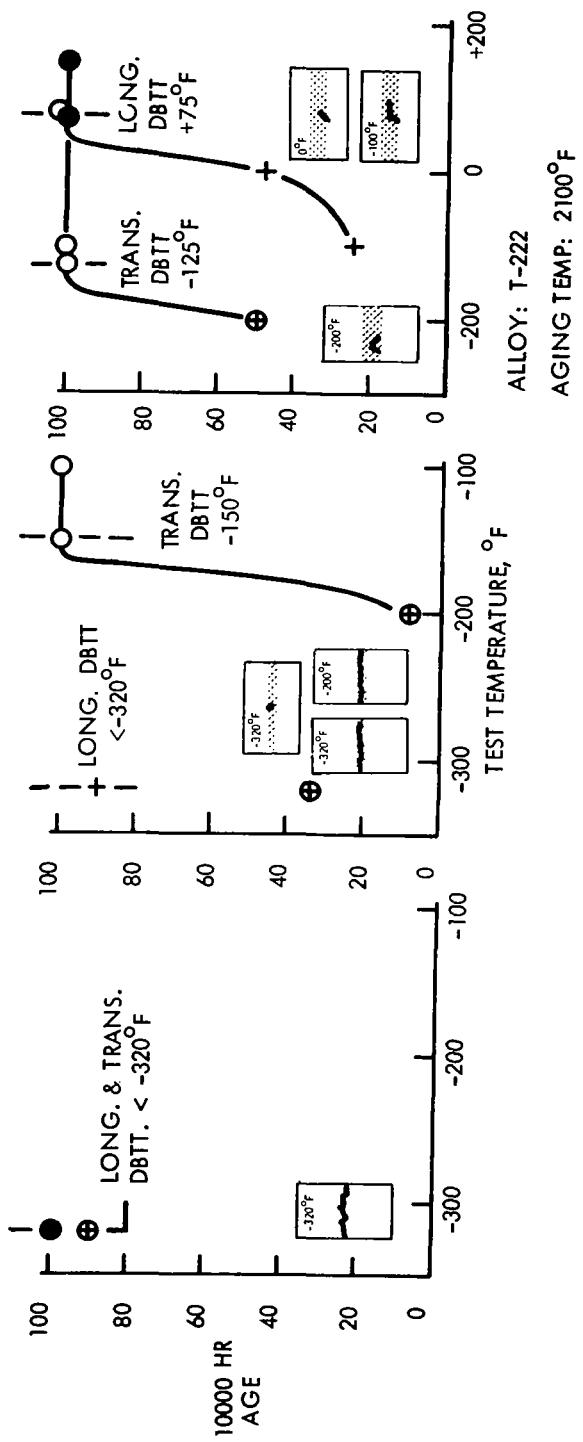
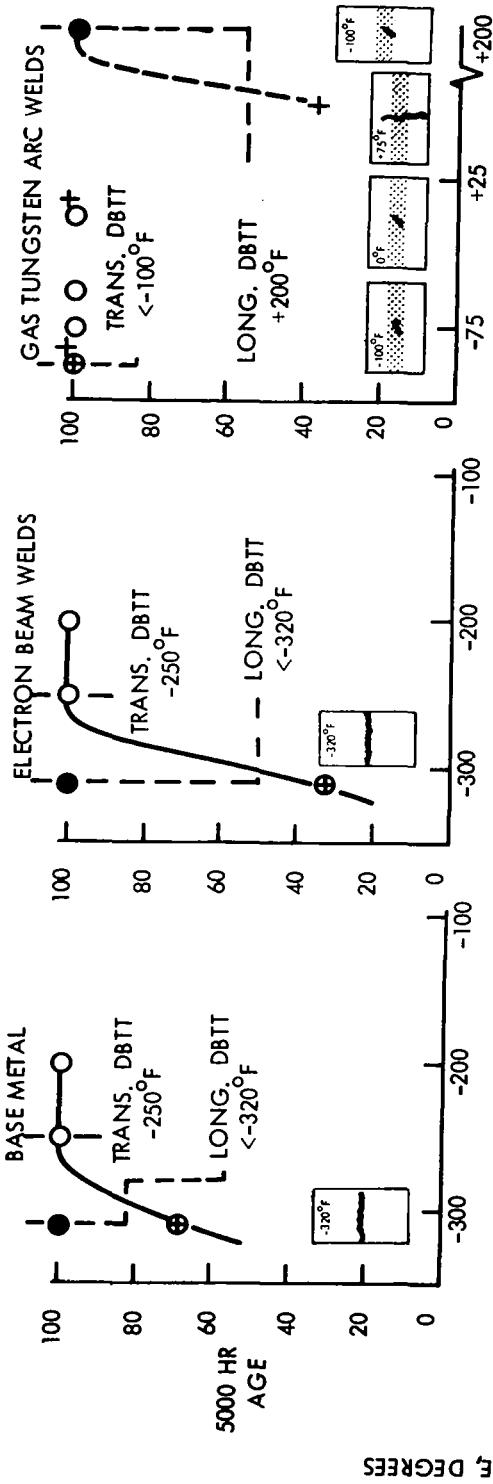
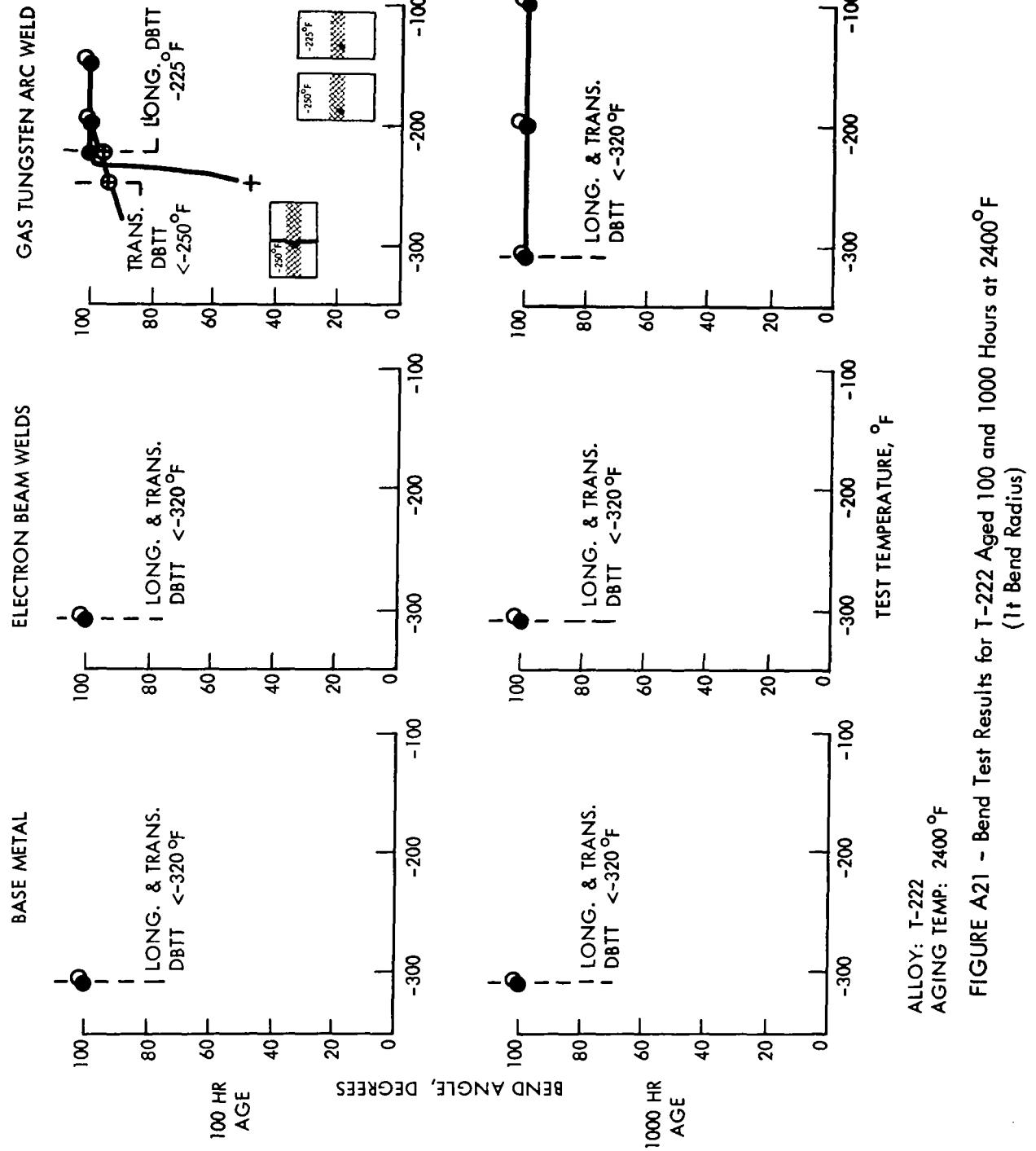


FIGURE A20 - Bend Test Results for T-222 Aged 5000 and 10,000 Hours at 2100°F (1 ft Bend Radius)



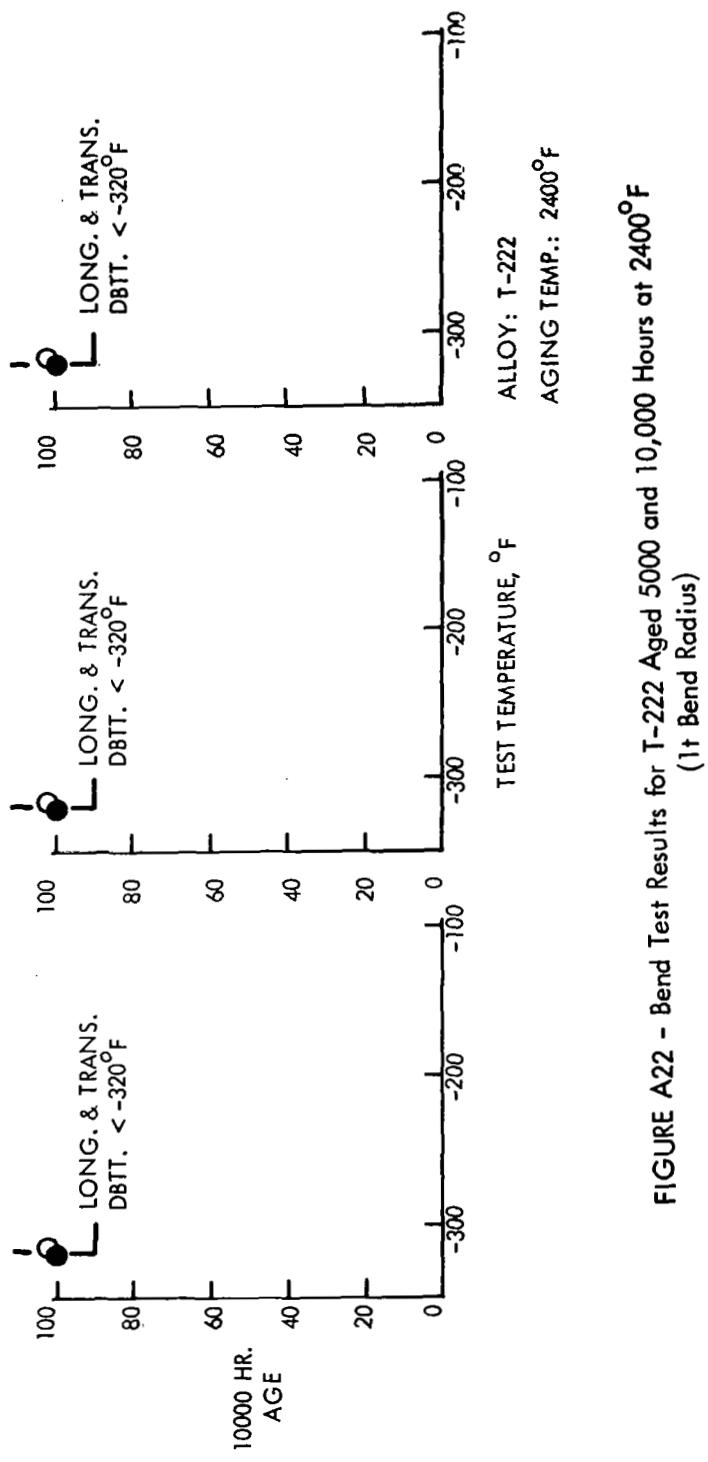
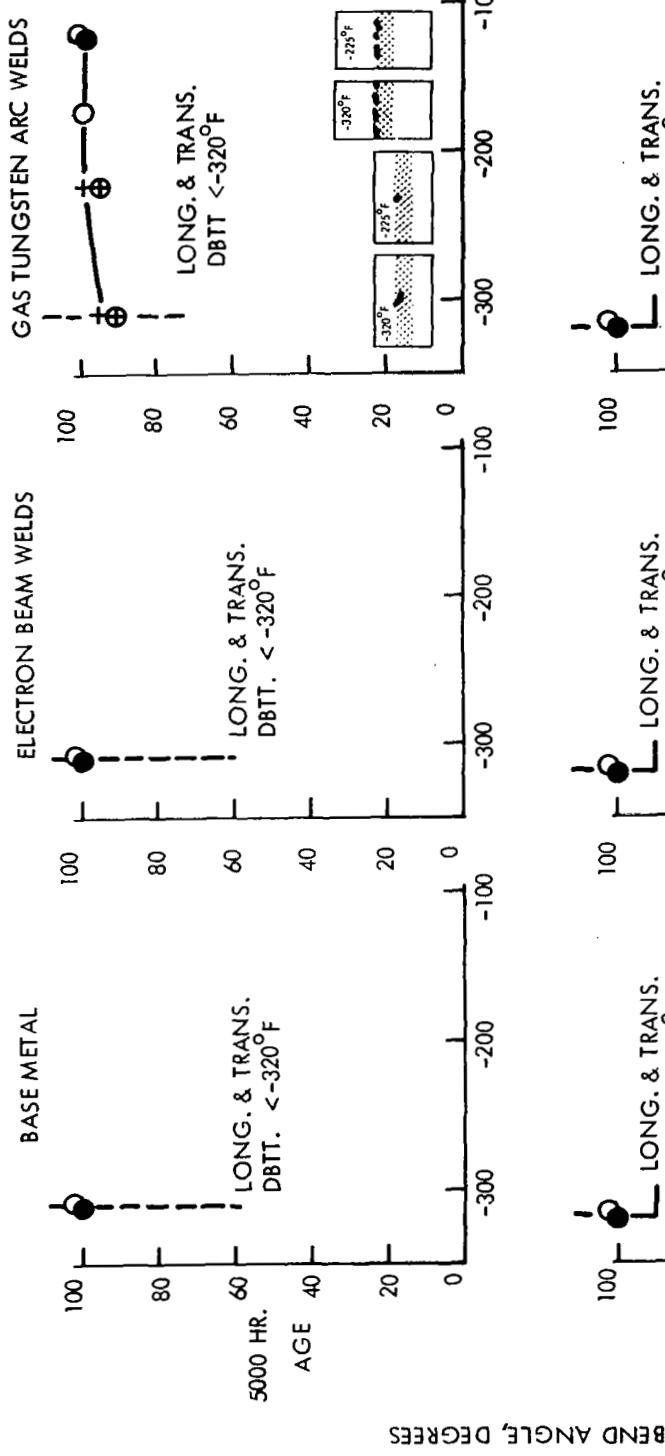


FIGURE A22 - Bend Test Results for T-222 Aged 5000 and 10,000 Hours at 2400°F
(1st Bend Radius)

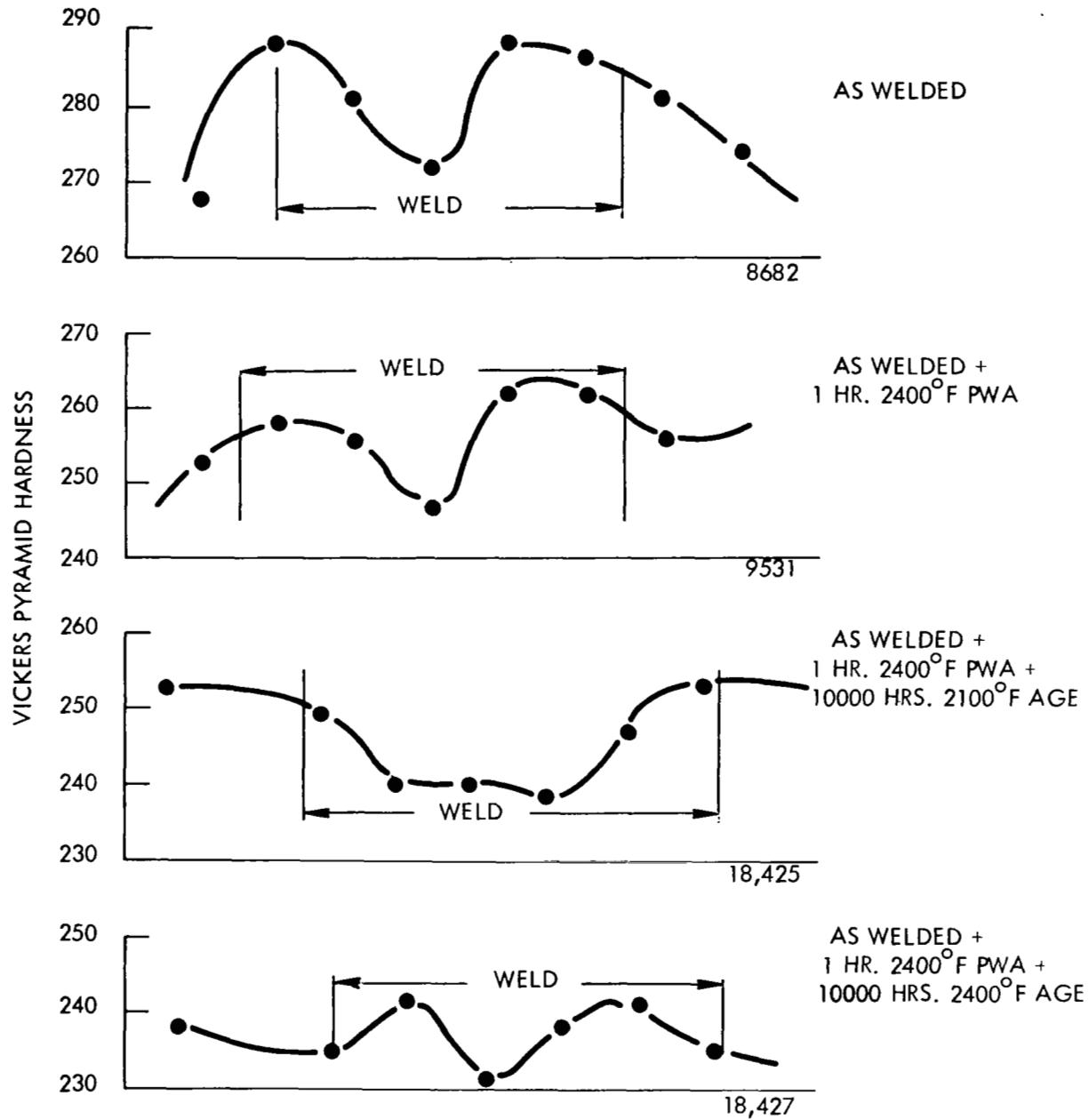
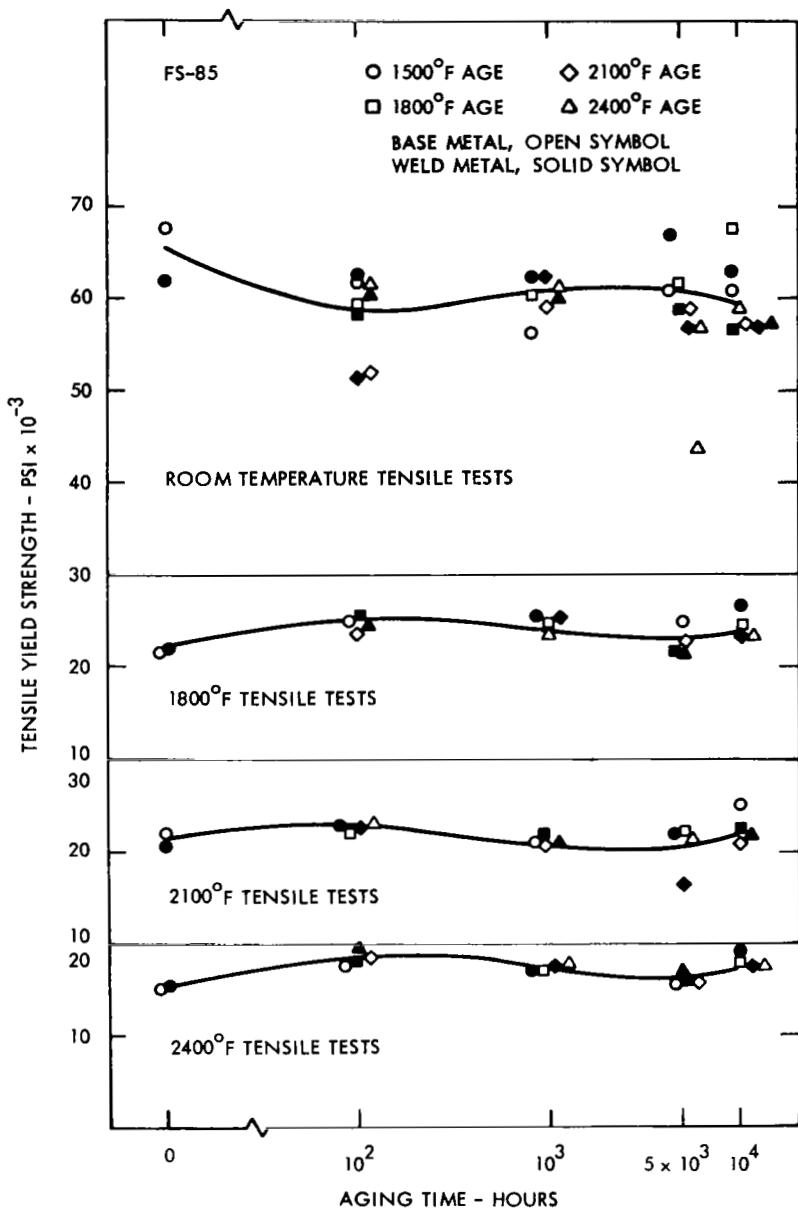
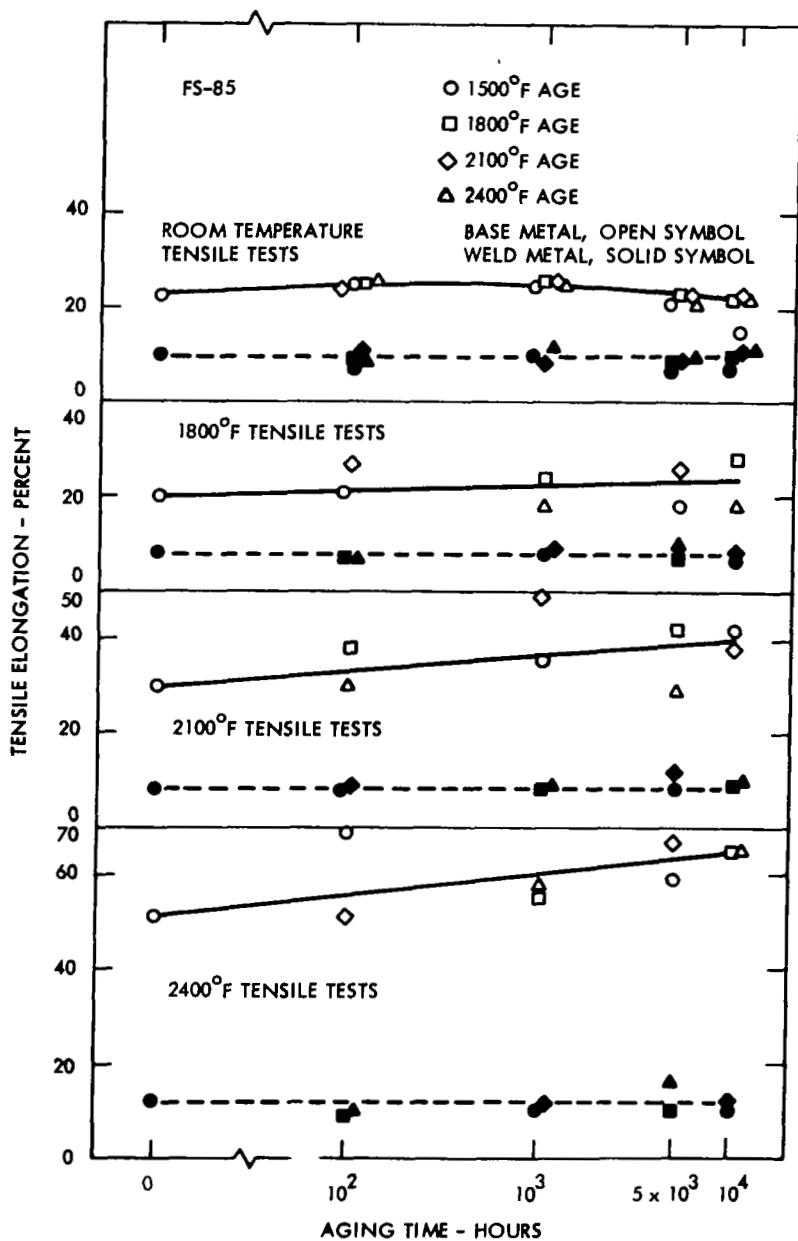


FIGURE A23 - Hardness Traverses for T-222 GTA Sheet Welds. Thermal History as Indicated. (10 Kg Load on Vickers Hardness Tester)



NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hour at 2400°F Prior to Aging and Testing.

FIGURE A24 - Tensile Yield Strength of FS-85 as a Function of Aging Parameters

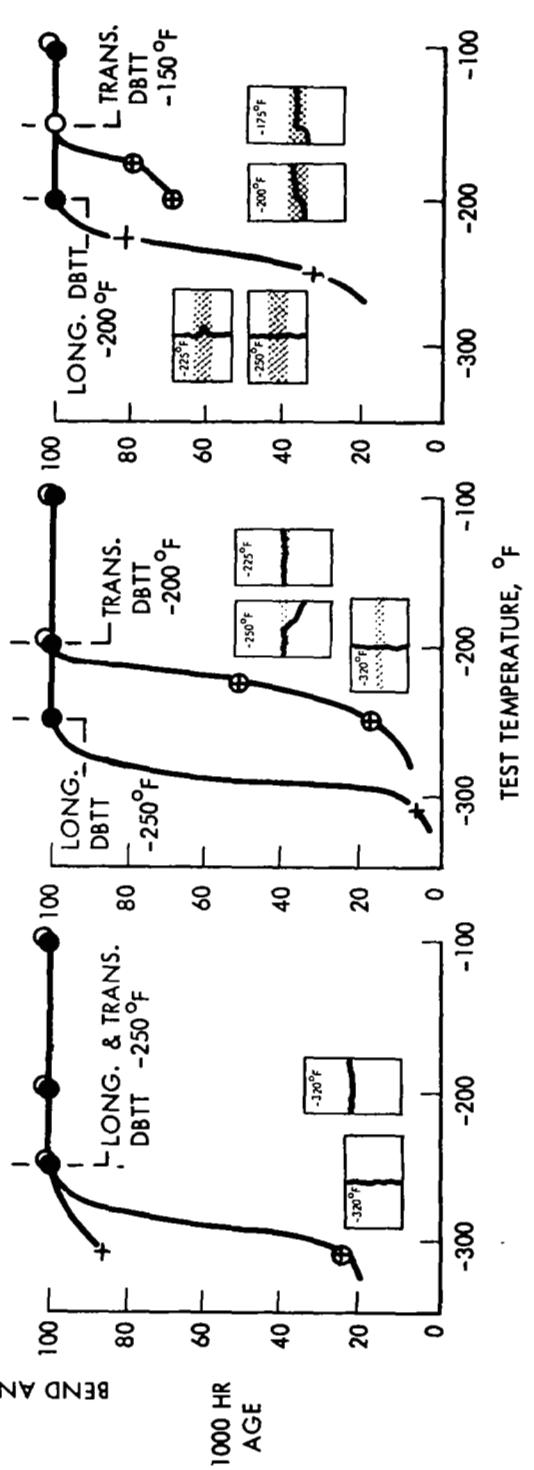
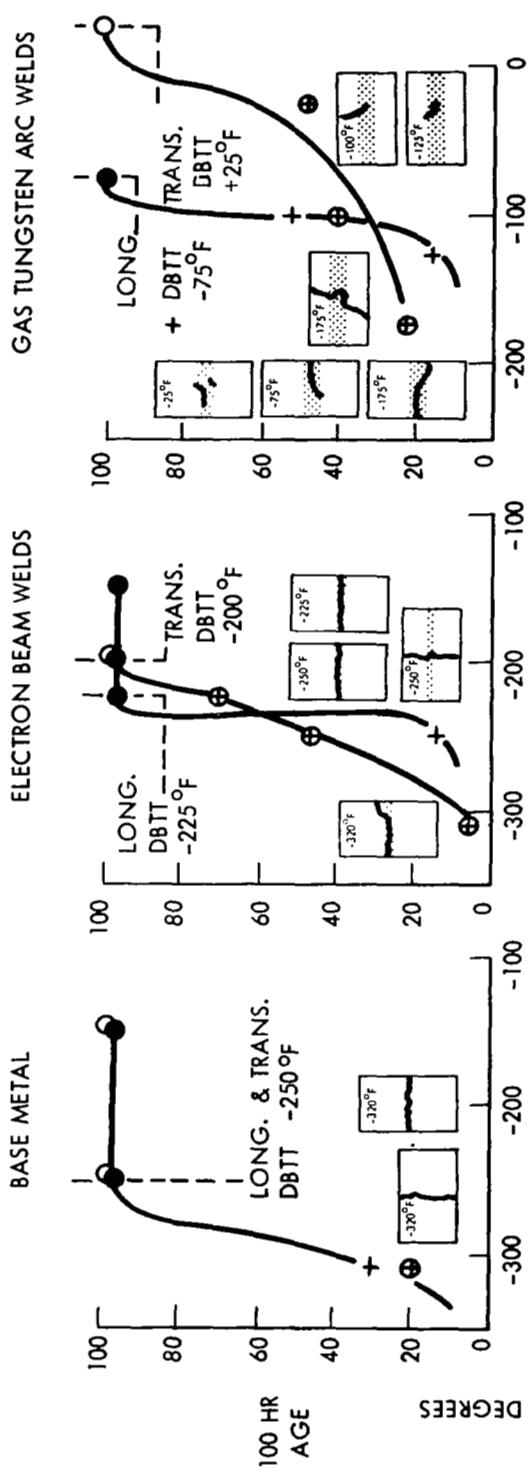


NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hour at 2400°F Prior to Aging and Testing.

FIGURE A25 - Tensile Elongation of FS-85 as a Function or Aging Parameters

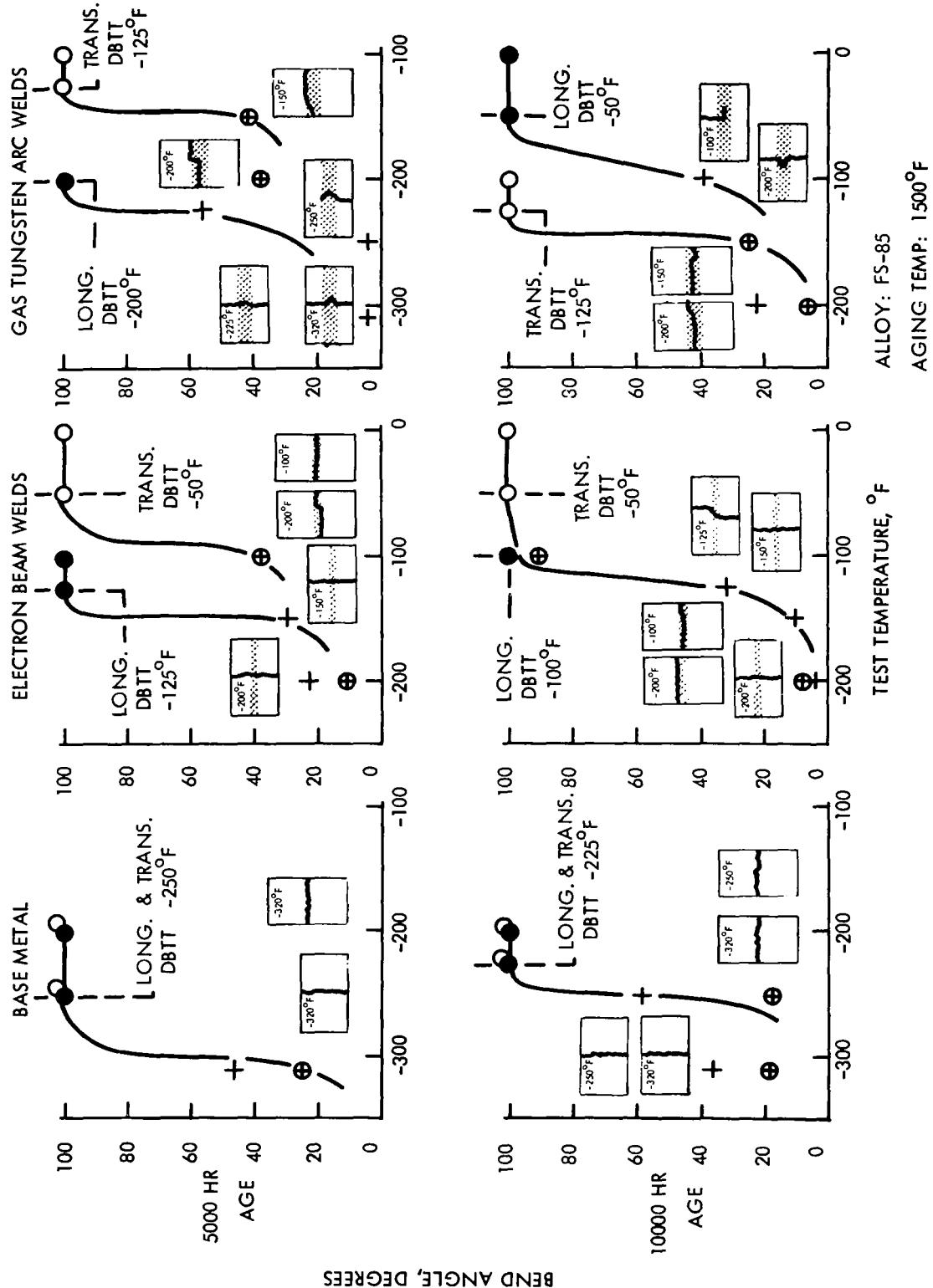
BASE METAL

ELECTRON BEAM WELDS



ALLOY: FS-85
AGING TEMP: 1500 °F

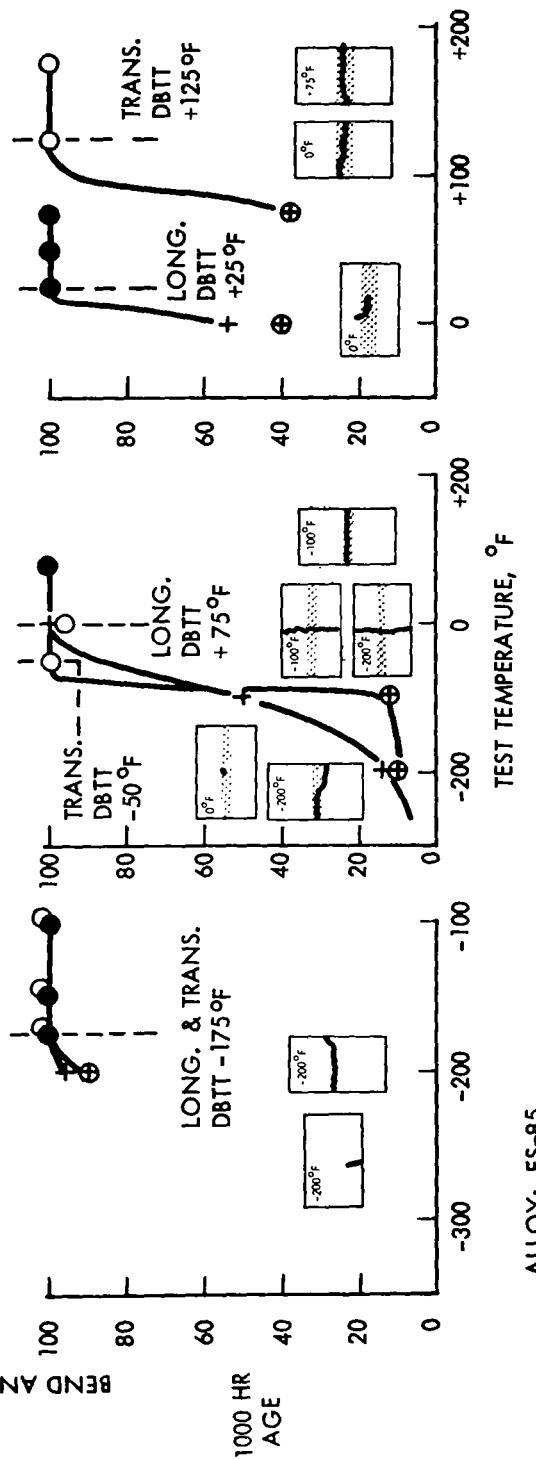
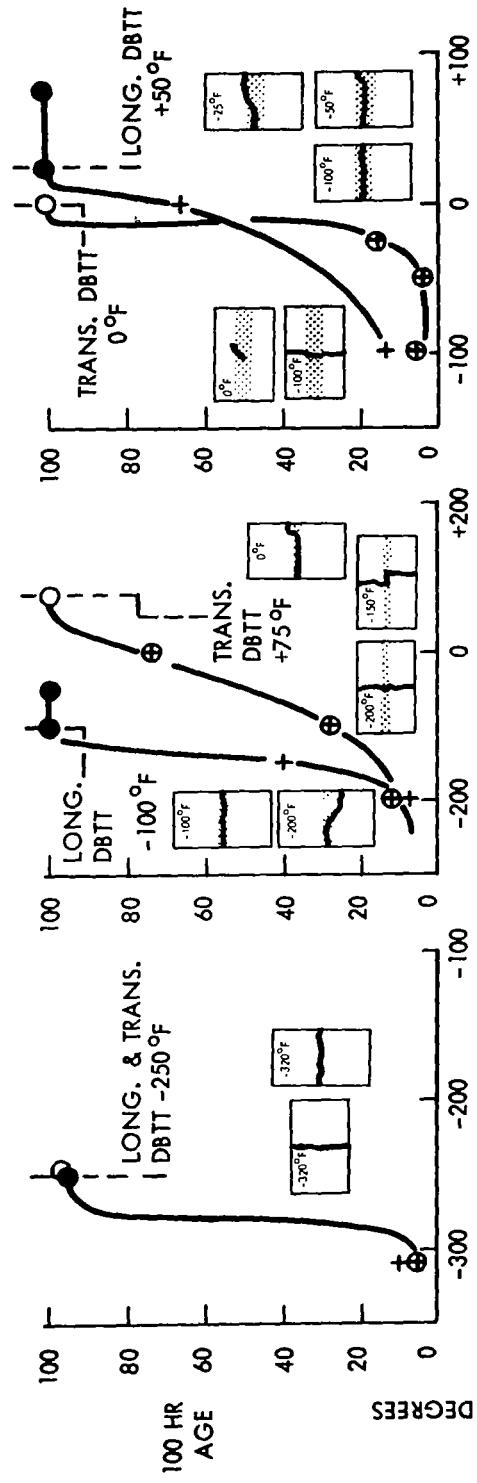
FIGURE A26 - Bend Test Results for FS-85 Aged 100 and 1000 Hours at 1500°F
(2t Bend Radius)



BASE METAL

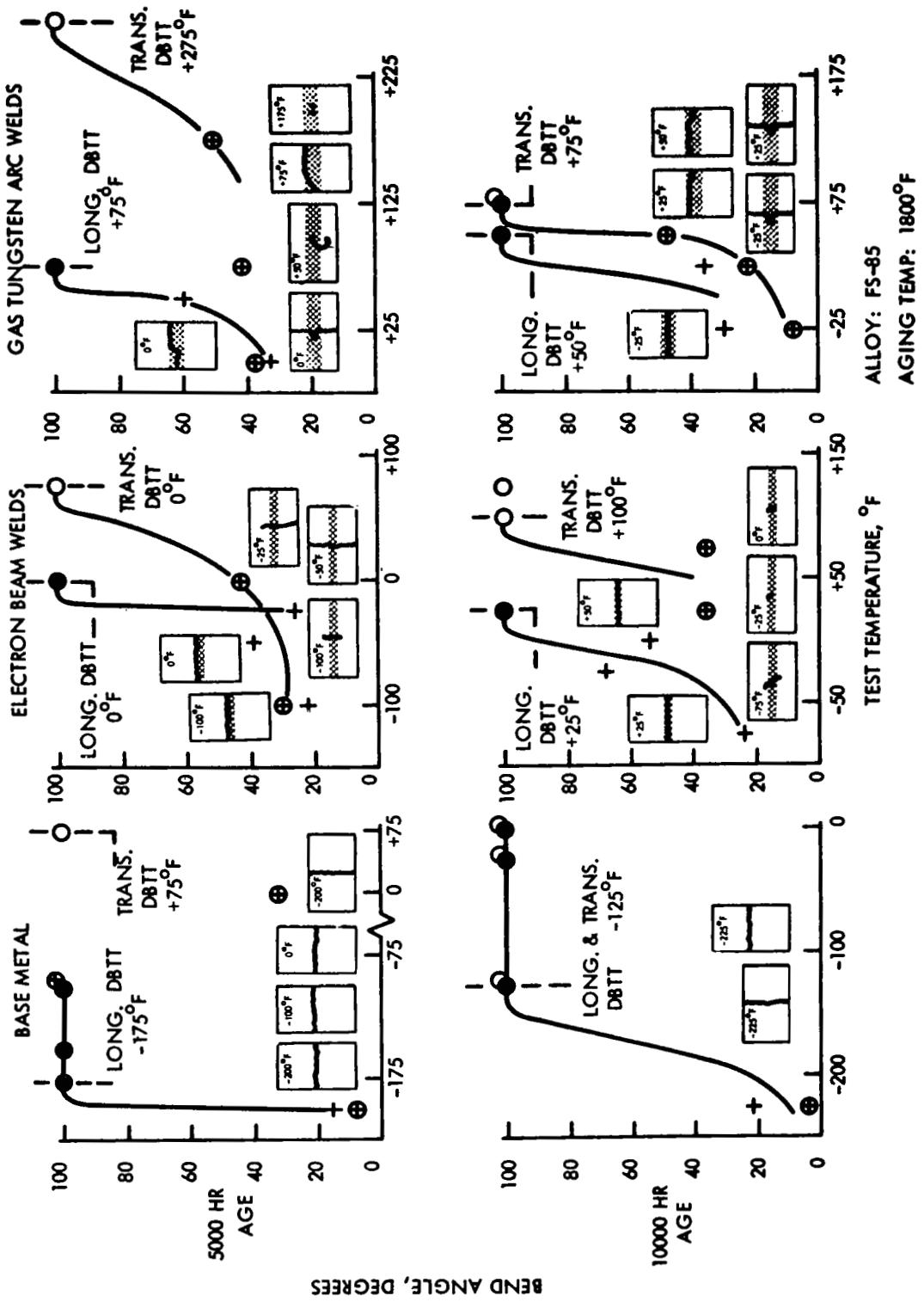
ELECTRON BEAM WELDS

GAS TUNGSTEN ARC WELDS



ALLOY: FS-85
AGING TEMP: 1800 °F

FIGURE A28 - Bend Test Results for FS-85 Aged 100 and 1000 Hours at 1800°F
(2t Bend Radius)



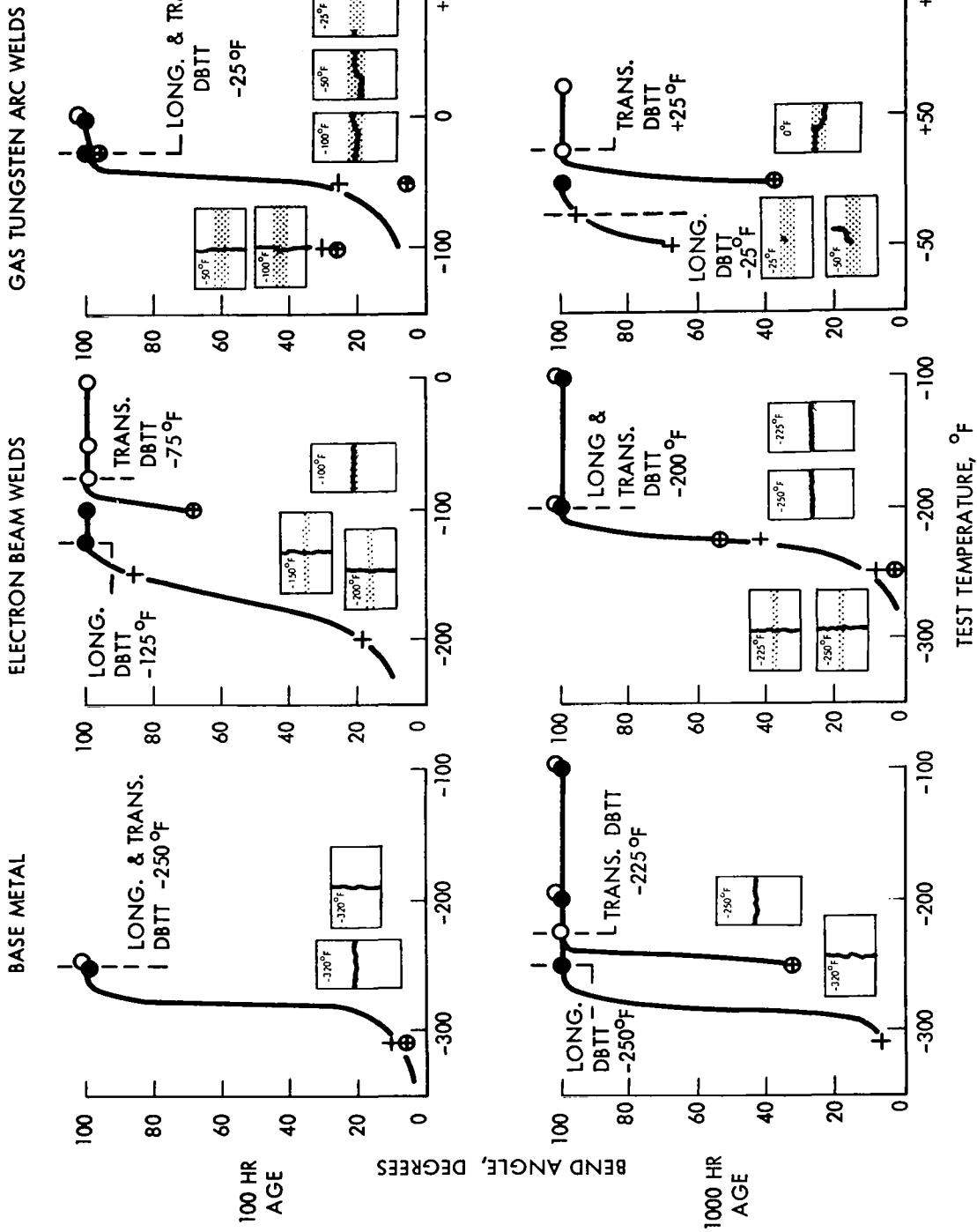


FIGURE A30 - Bend

FS-85 Aged 100 and 1000 Hours at 2100°F
(2 $\frac{1}{2}$ Bend Radius)

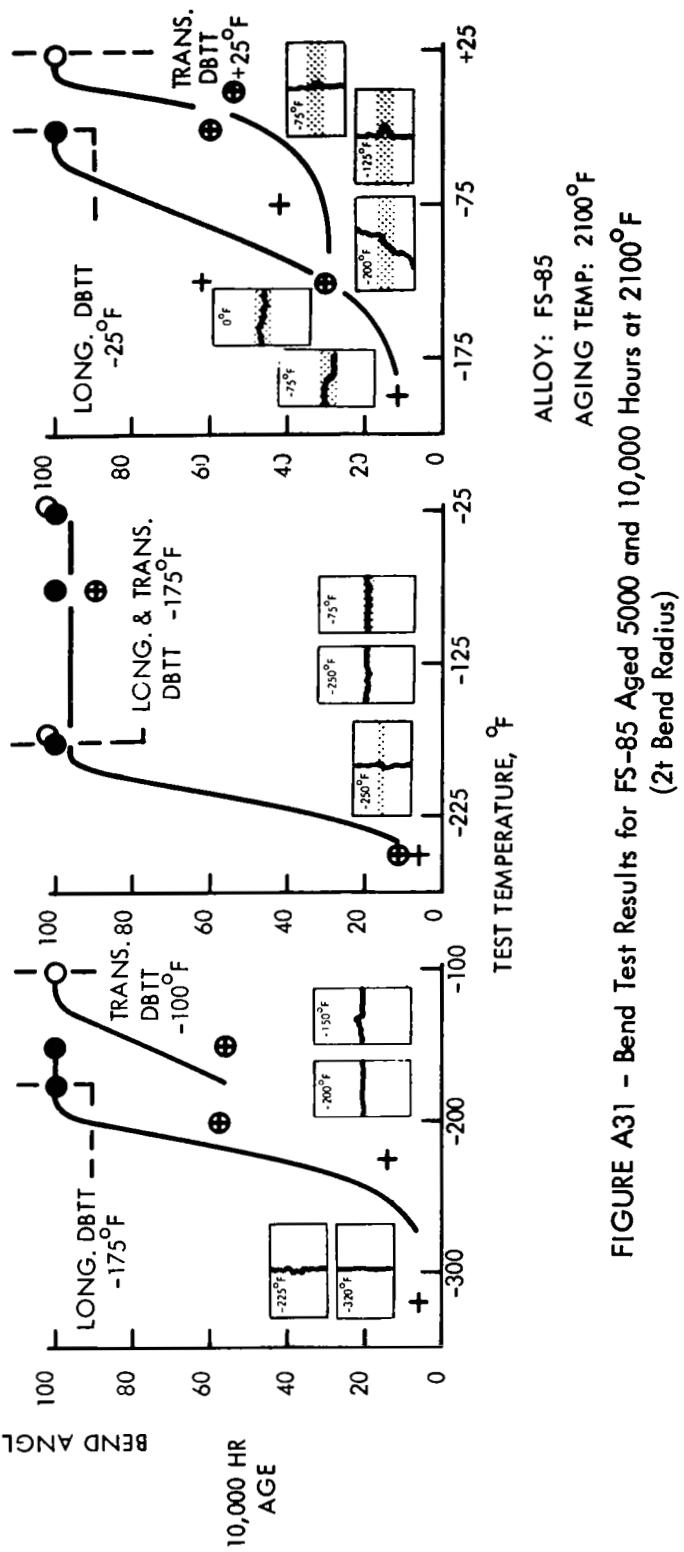
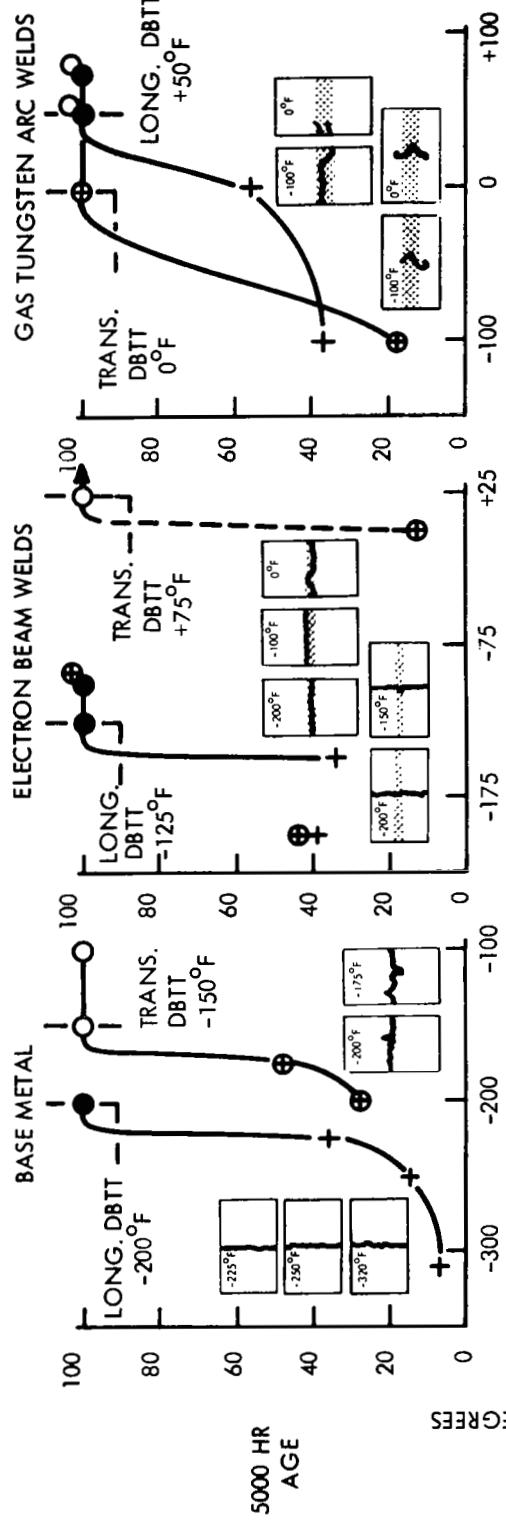
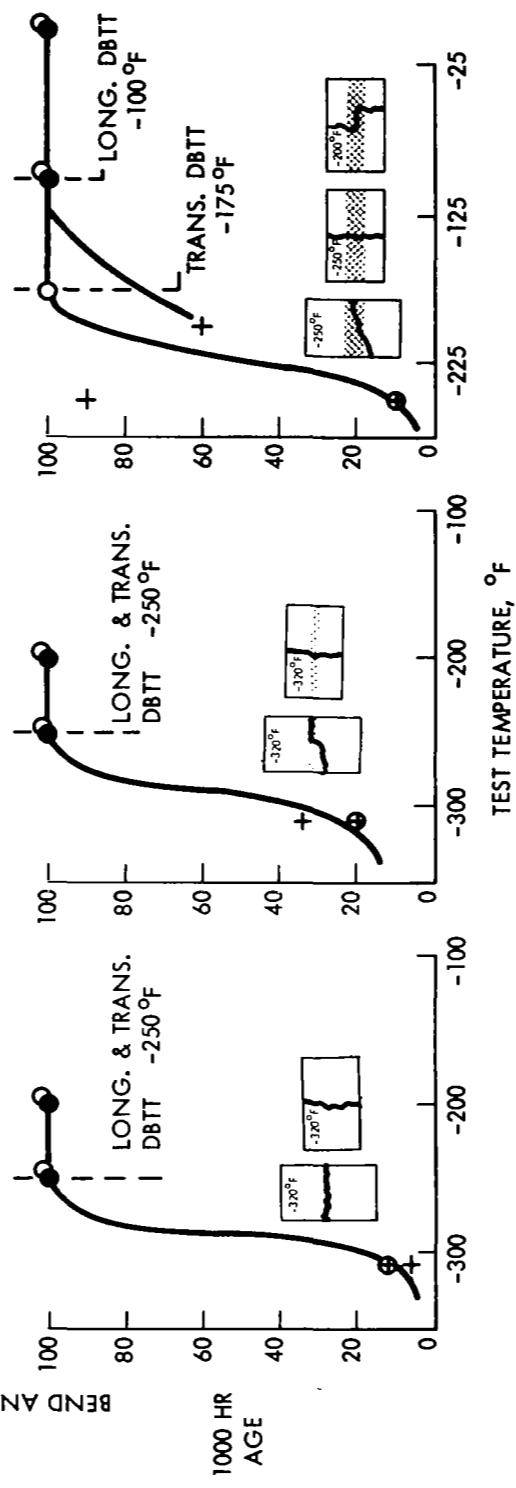
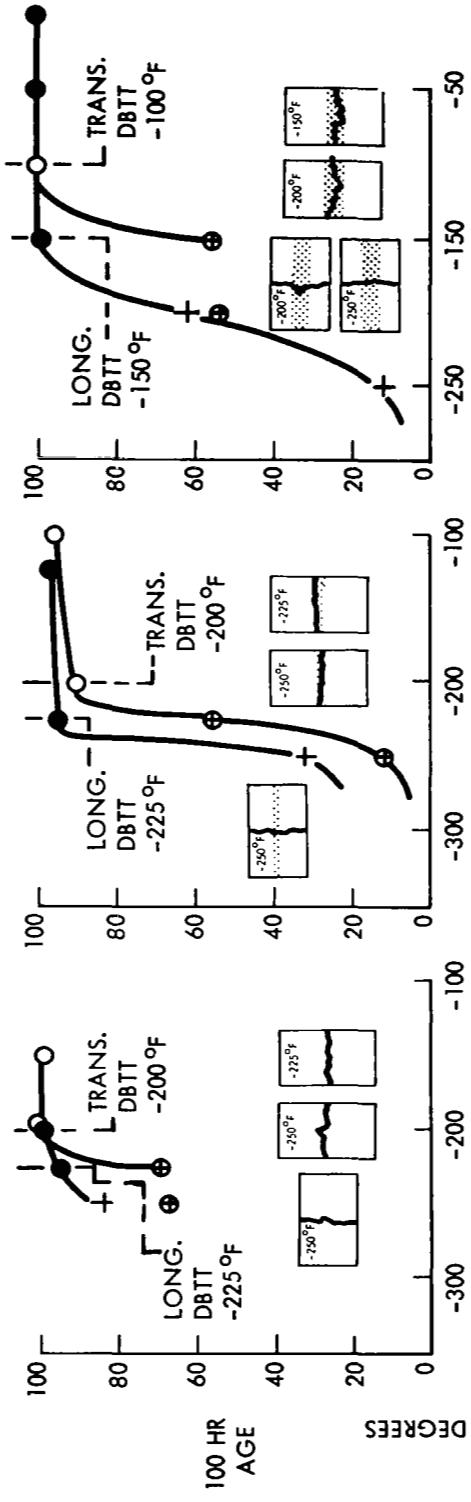


FIGURE A31 – Bend Test Results for FS-85 Aged 5000 and 10,000 Hours at 2100°F
 (2^t Bend Radius)
 ALLOY: FS-85
 AGING TEMP: 2100°F

GAS TUNGSTEN ARC WELDS

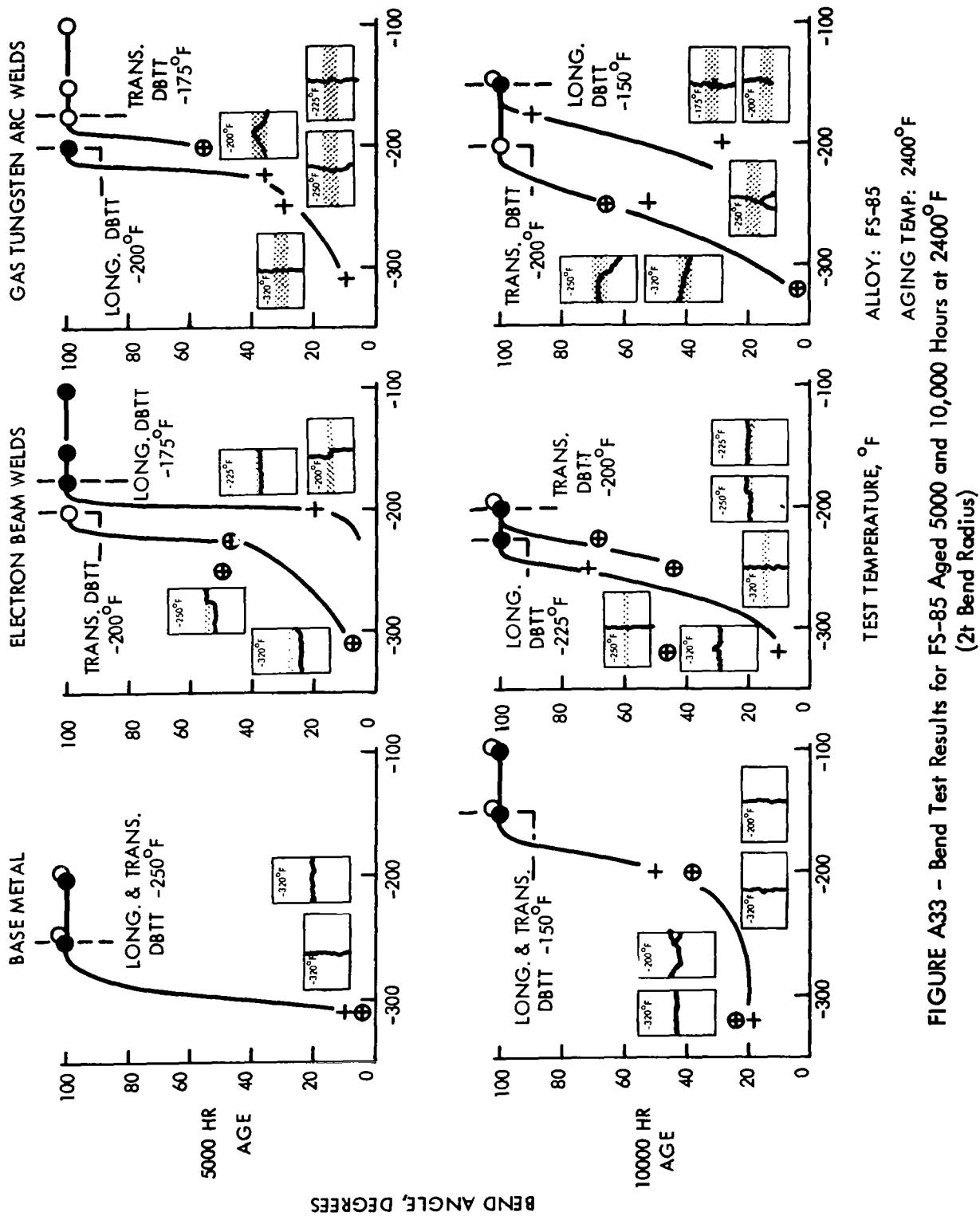
ELECTRON BEAM WELDS

BASE METAL



ALLOY: FS-85
AGING TEMP: 2400°F

FIGURE A32 - Bend Test Results for FS-85 Aged 100 and 1000 Hours at 2400°F
(2t Bend Radius)



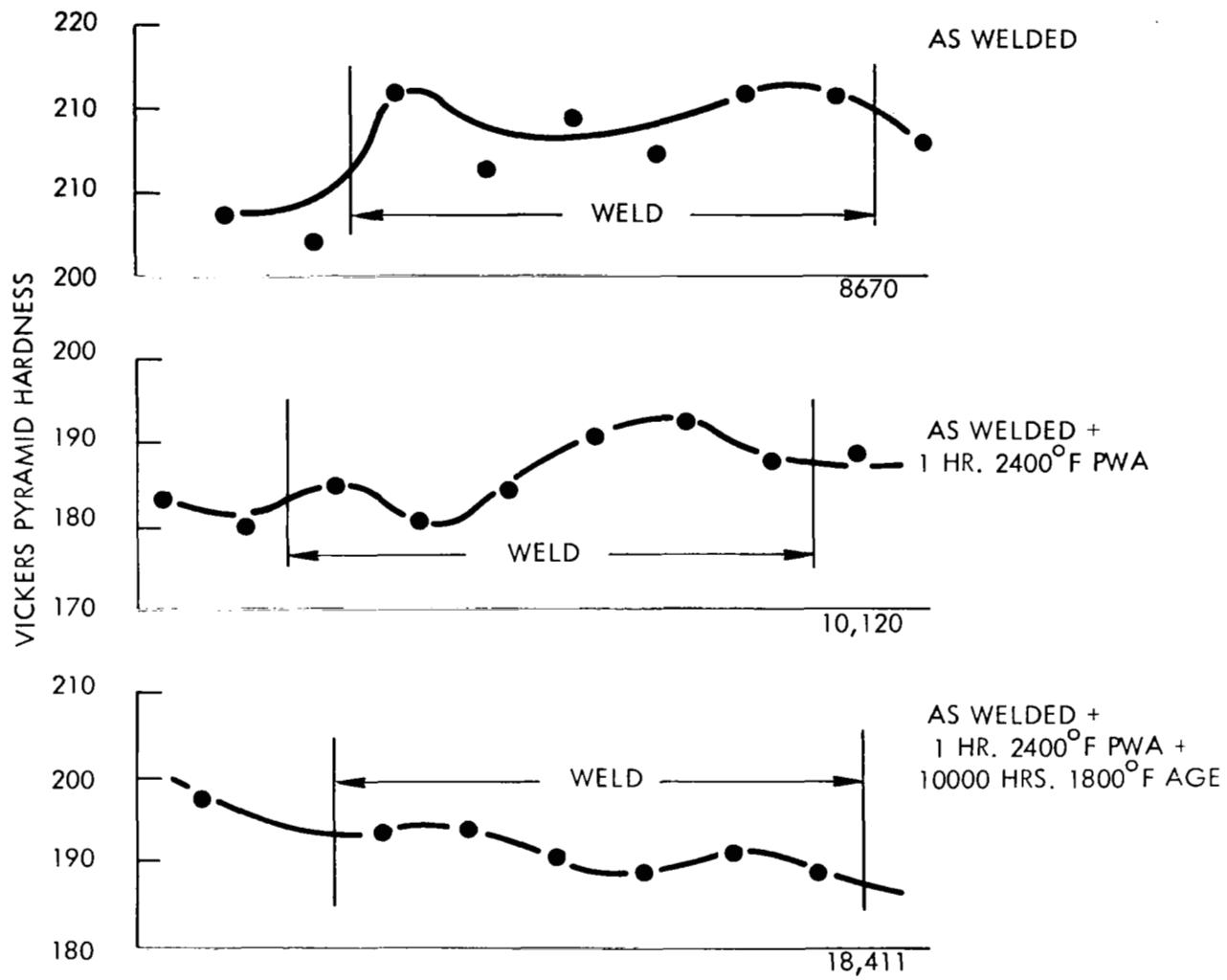
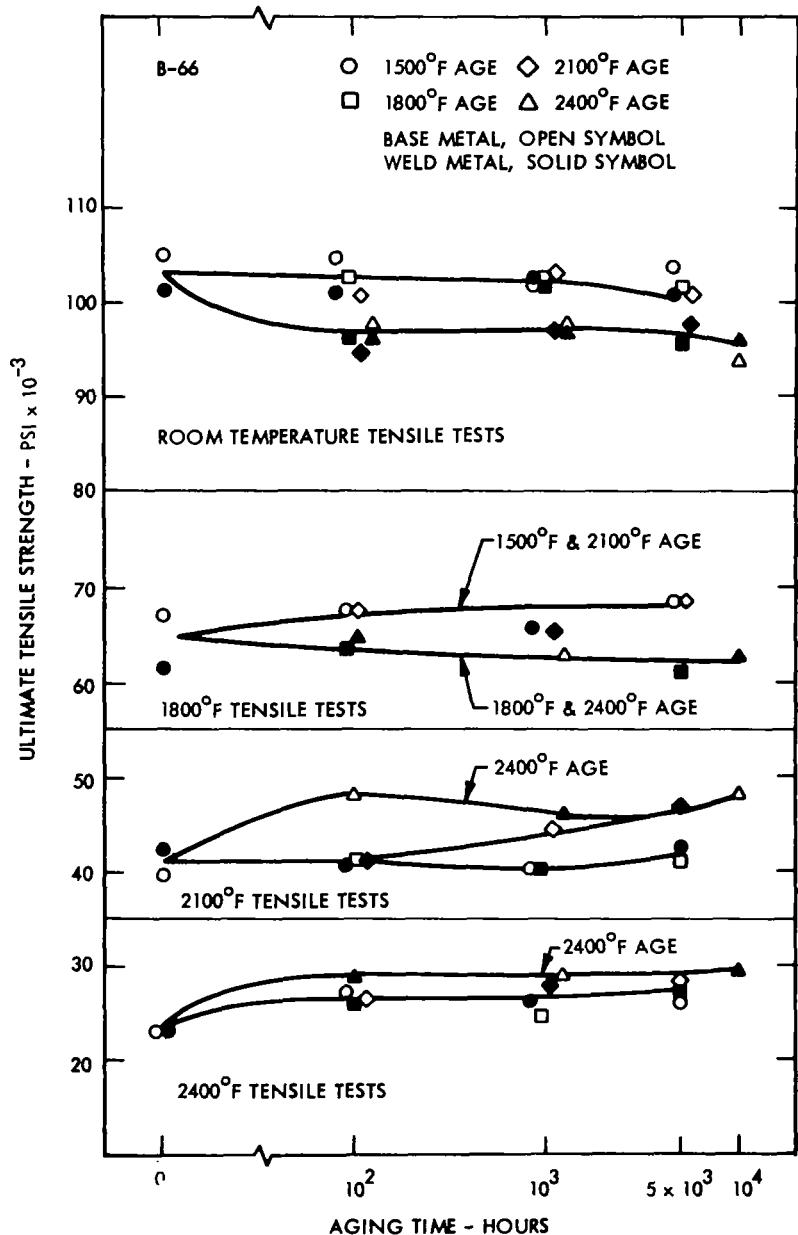
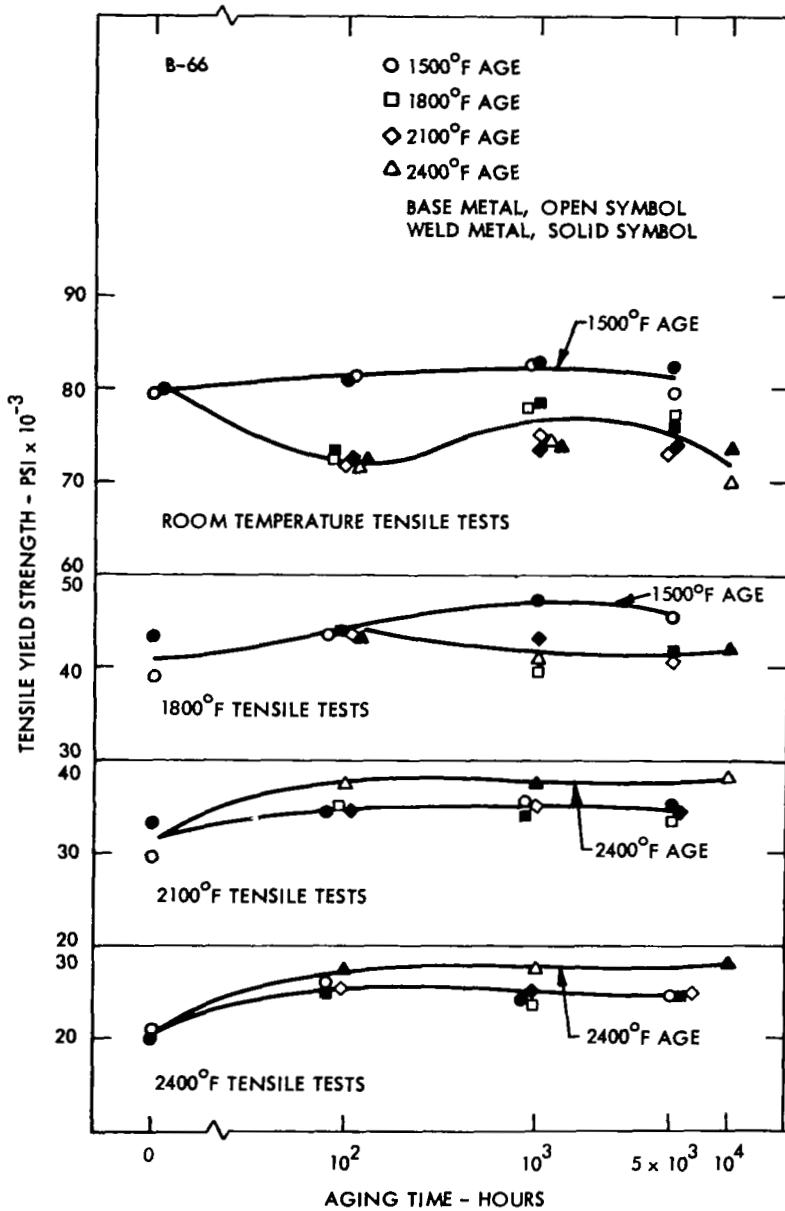


FIGURE A34 – Hardness Traverses for FS-85 GTA Sheet Welds. Thermal History as Indicated. (10 Kg Load on Vickers Hardness Tester)



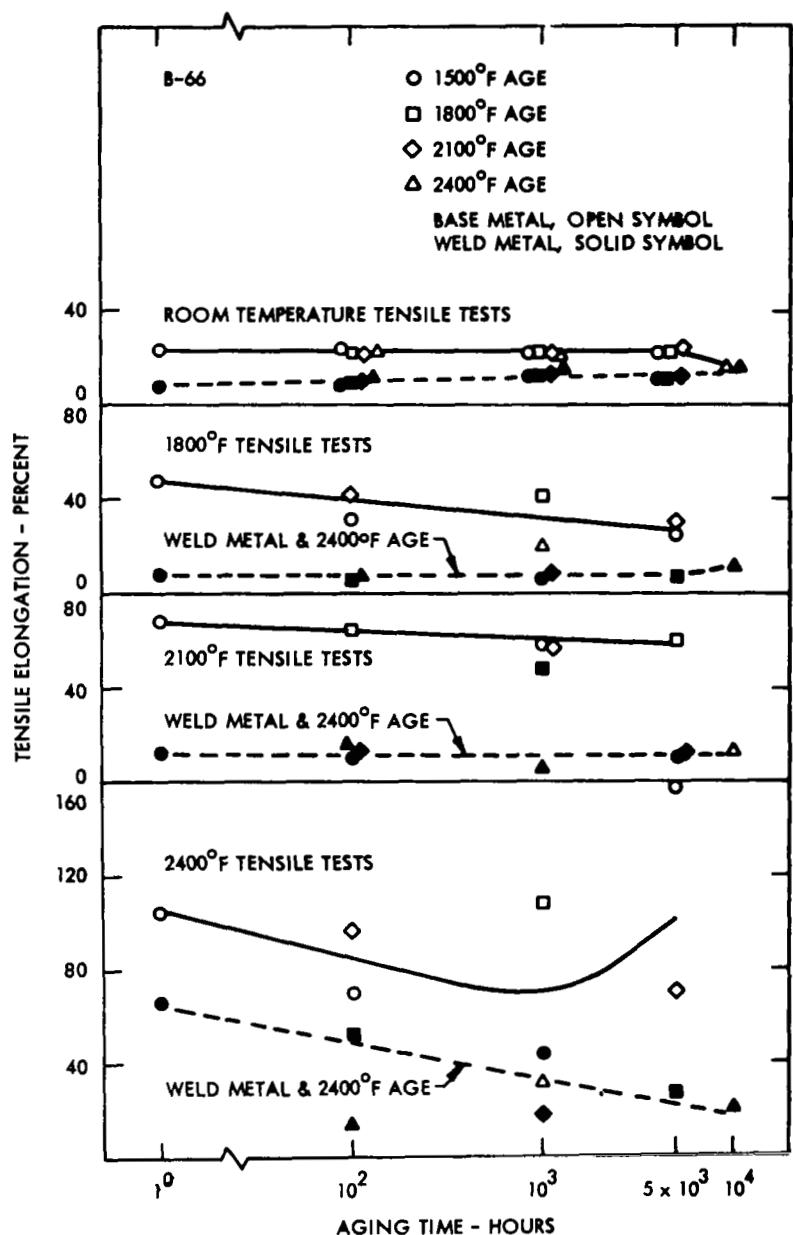
NOTE: Optimum Weld Parameters, Samples Not Post Weld Annealed
 Prior to Aging and Testing.

FIGURE A35 - Ultimate Tensile Strength of B-66 as a Function of Aging Parameters



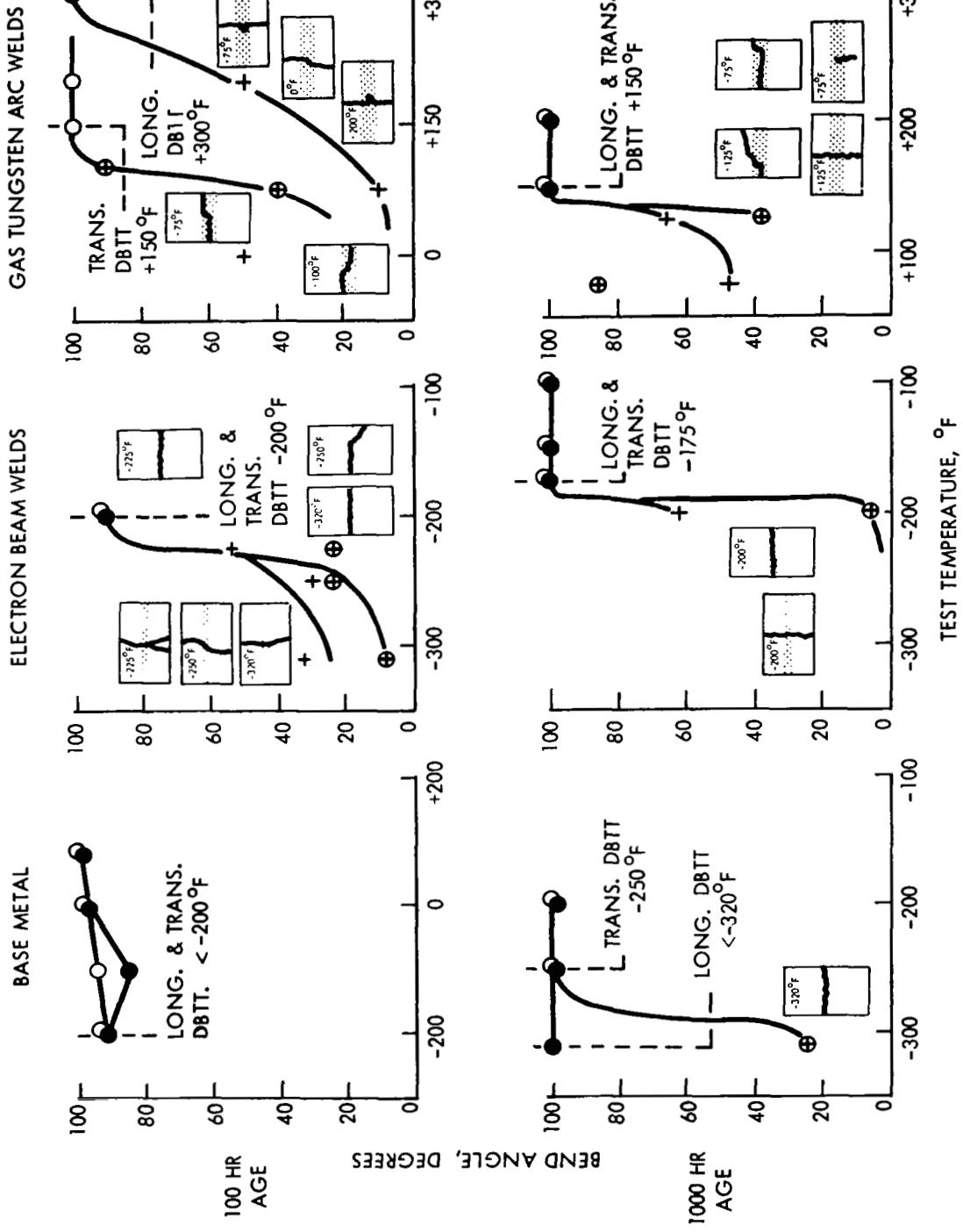
NOTE: Optimum Weld Parameters, Samples Not Post Weld Annealed
Prior to Aging and Testing.

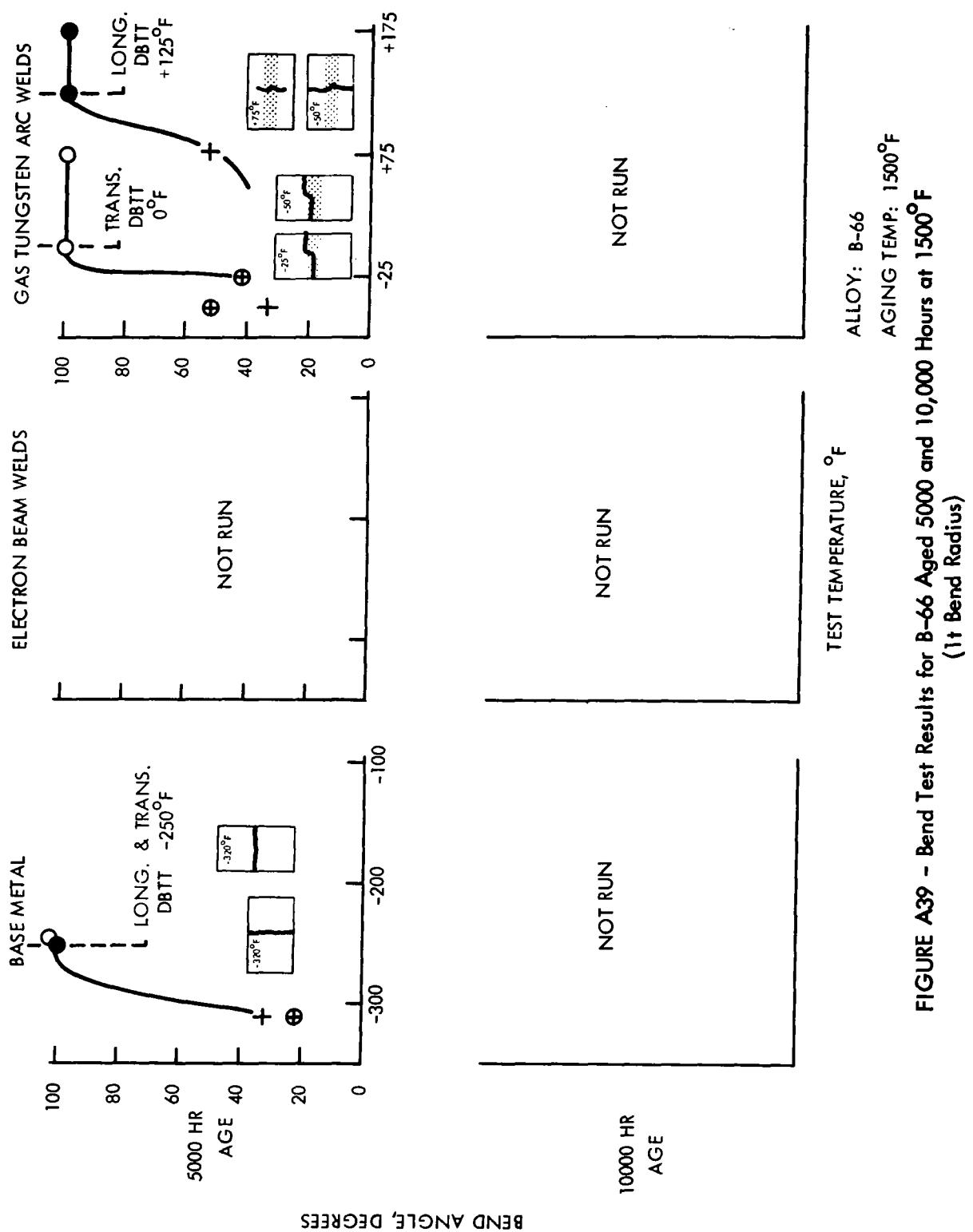
FIGURE A36 - Tensile Yield Strength of B-66 as a Function of Aging Parameters

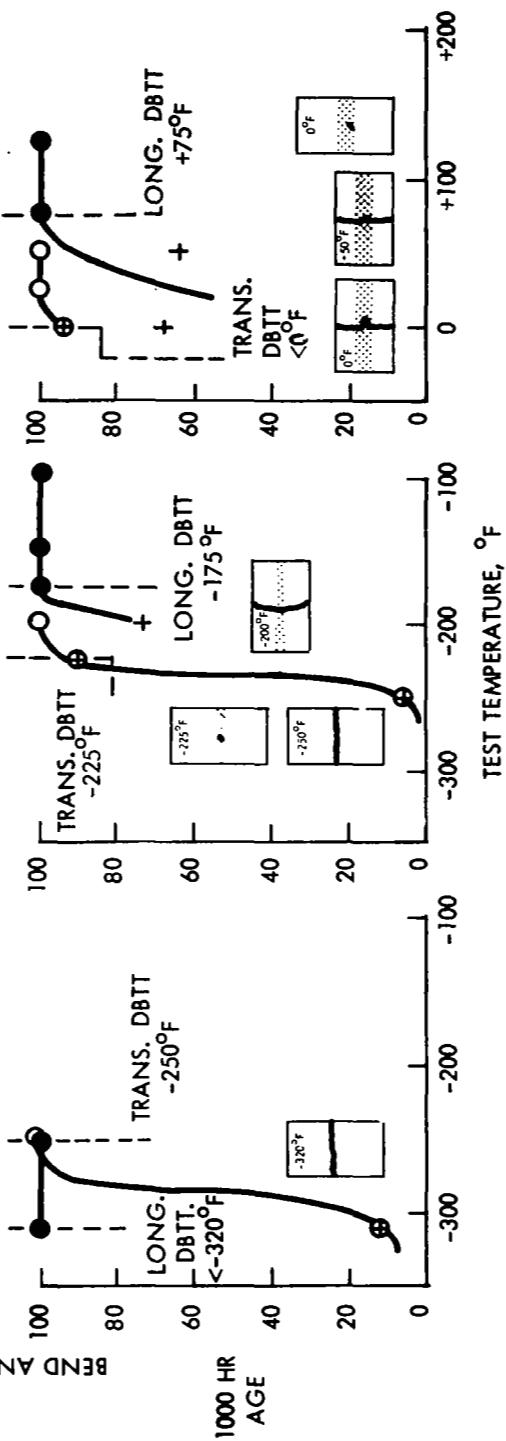
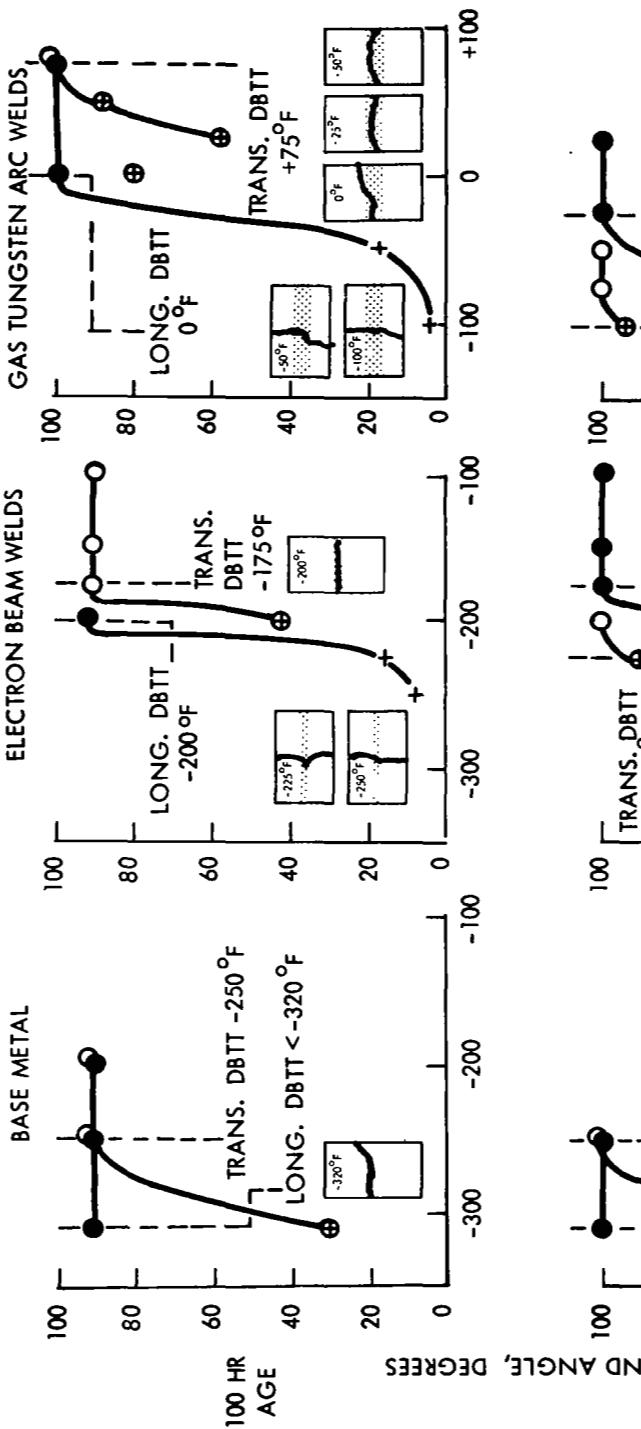


NOTE: Optimum Weld Parameters, Samples Not Post Weld Annealed Prior to Aging and Testing.

FIGURE A37 - Tensile Elongation of B-66 as a Function of Aging Parameters

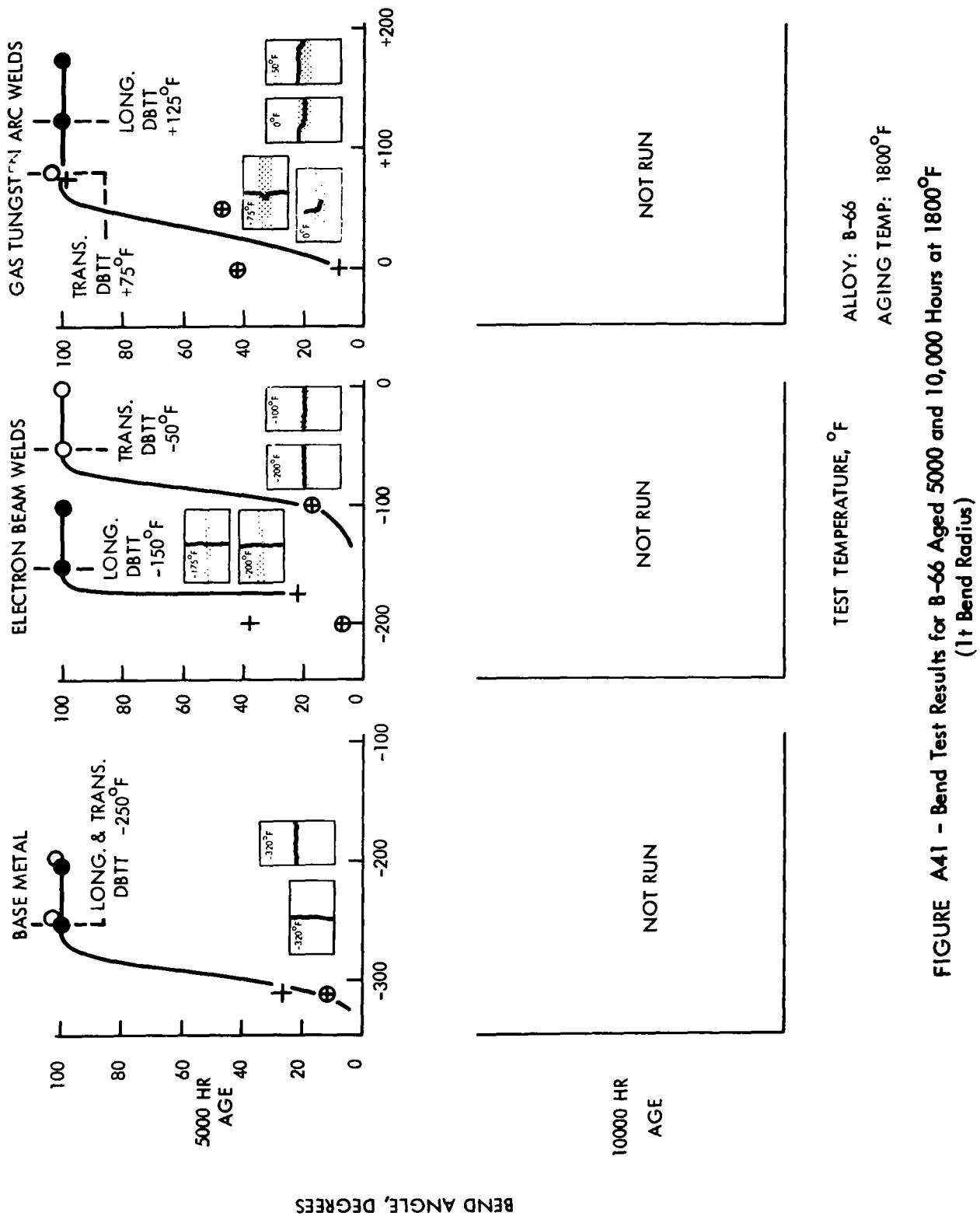






**FIGURE A40 - Bend Test Results for B-66 Aged 100 and 1000 Hours at 1800°F
(1 ft Bend Radius)**

ALLOY: B-66
AGING TEMP: 1800 °F



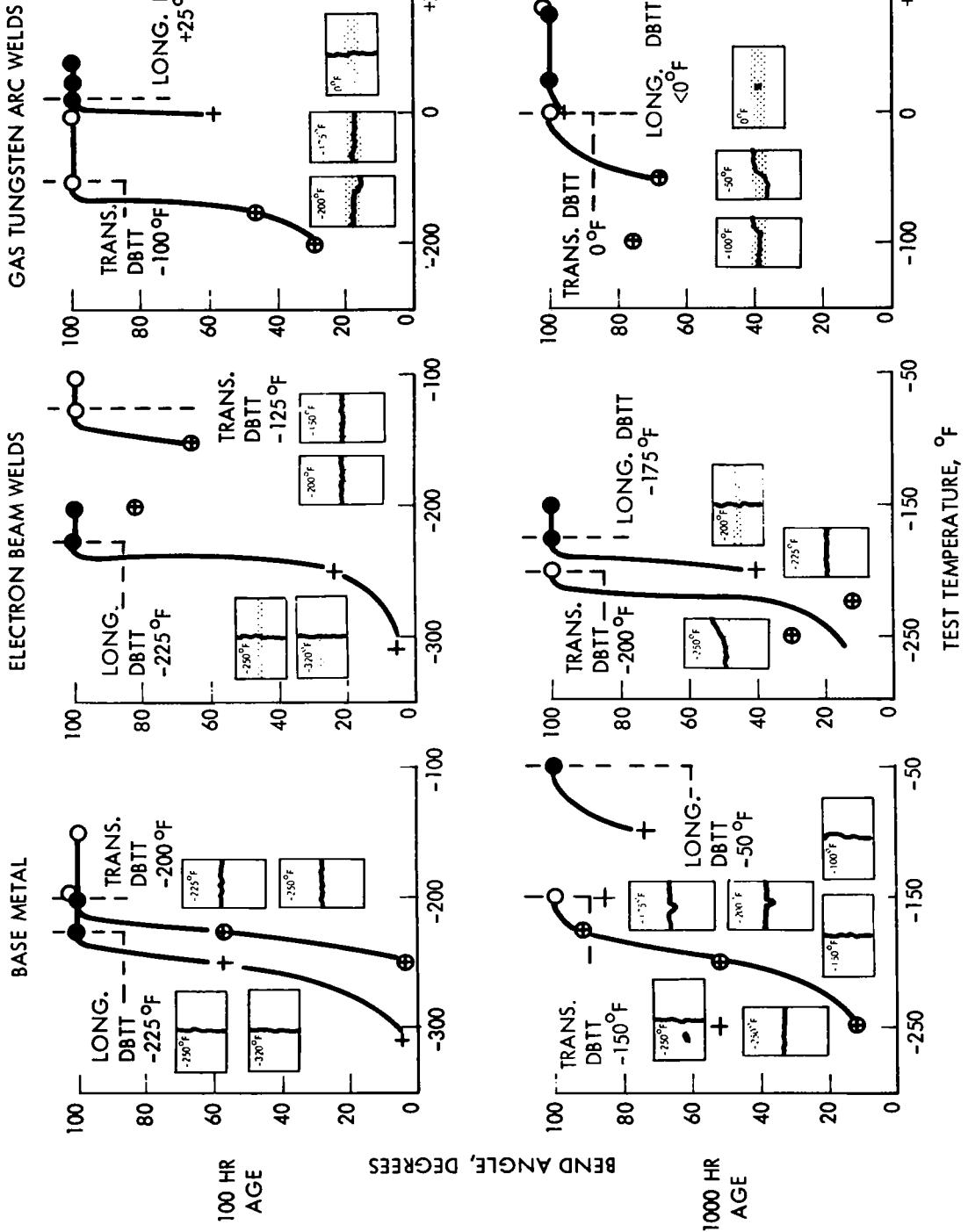
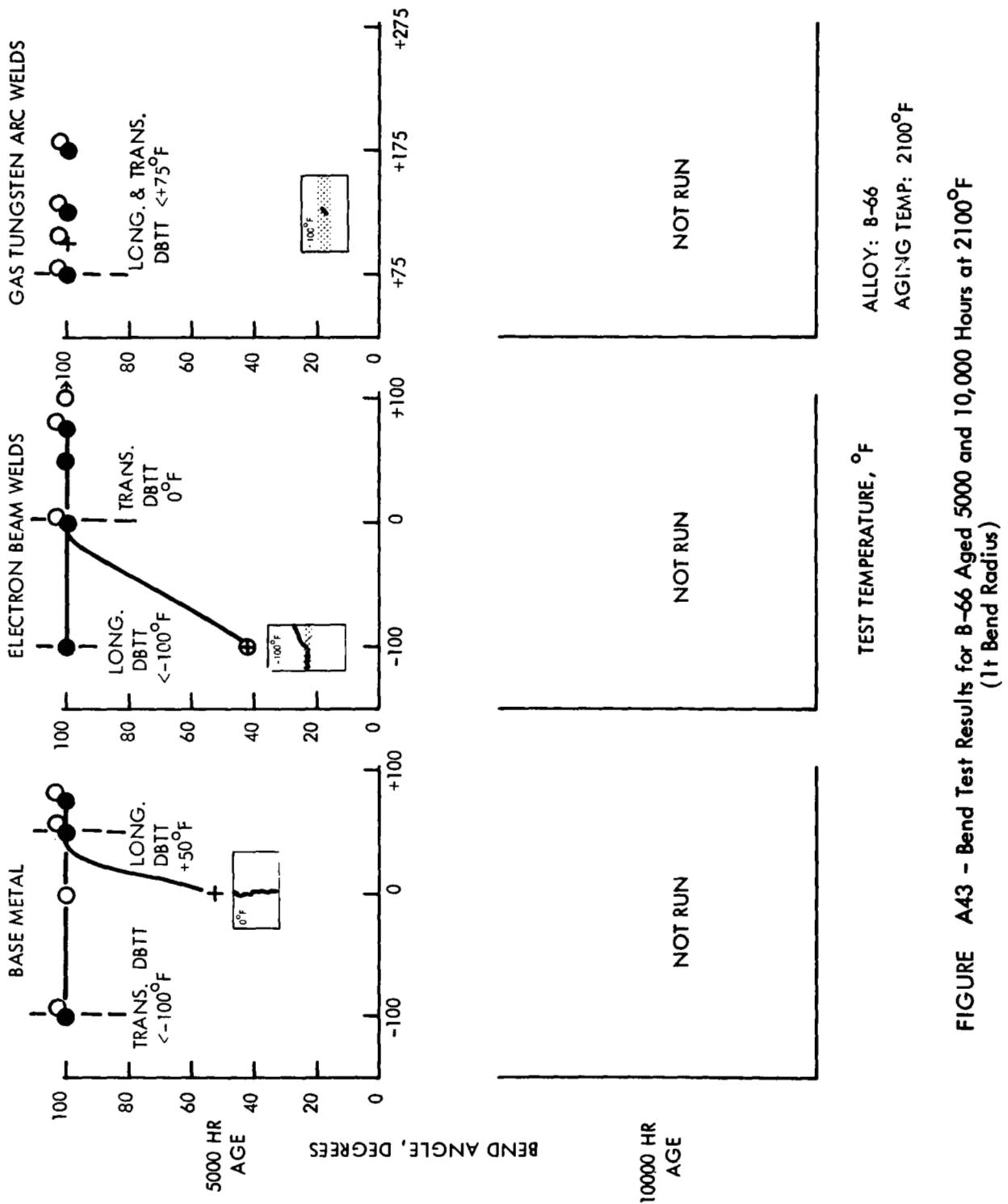


FIGURE A42 – Bend Test Results for B-66 Aged 100 and 1000 Hours at 2100°F
(1 ft Bend Radius)

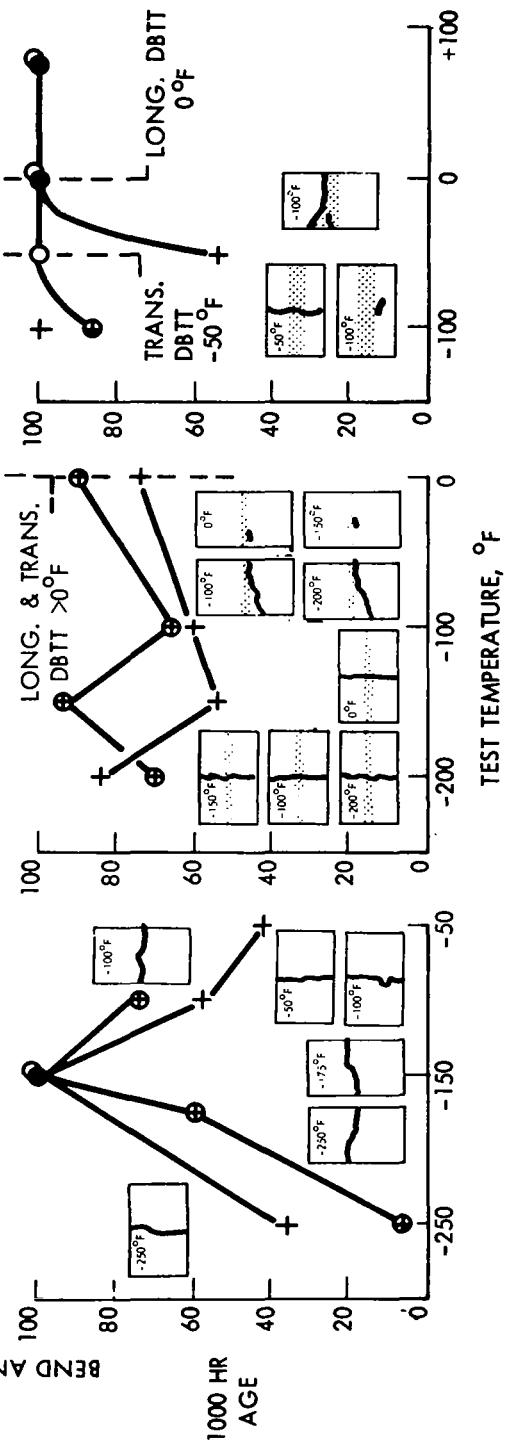
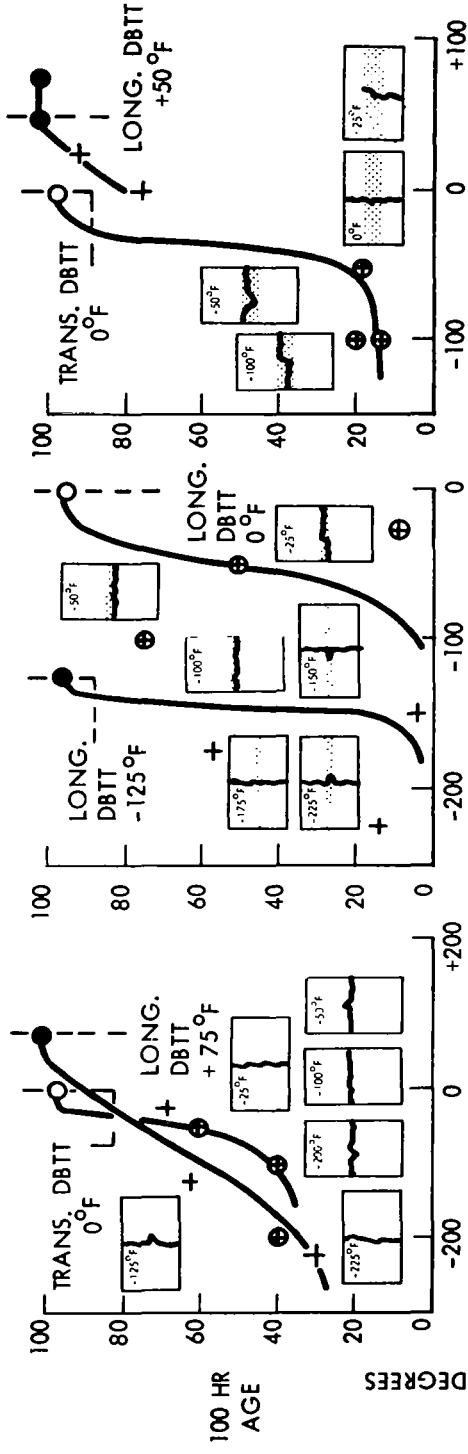


**FIGURE A43 - Bend Test Results for B-66 Aged 5000 and 10,000 Hours at 2100°F
(1† Bend Radius)**

GAS TUNGSTEN ARC WELD

ELECTRON BEAM WELD

BASE METAL



ALLOY: B-66
AGING TEMP: 2400°F

FIGURE A44 – Bend Test Results for B-66 Aged 100 and 1000 Hours at 2400°F
(1 ft Bend Radius)

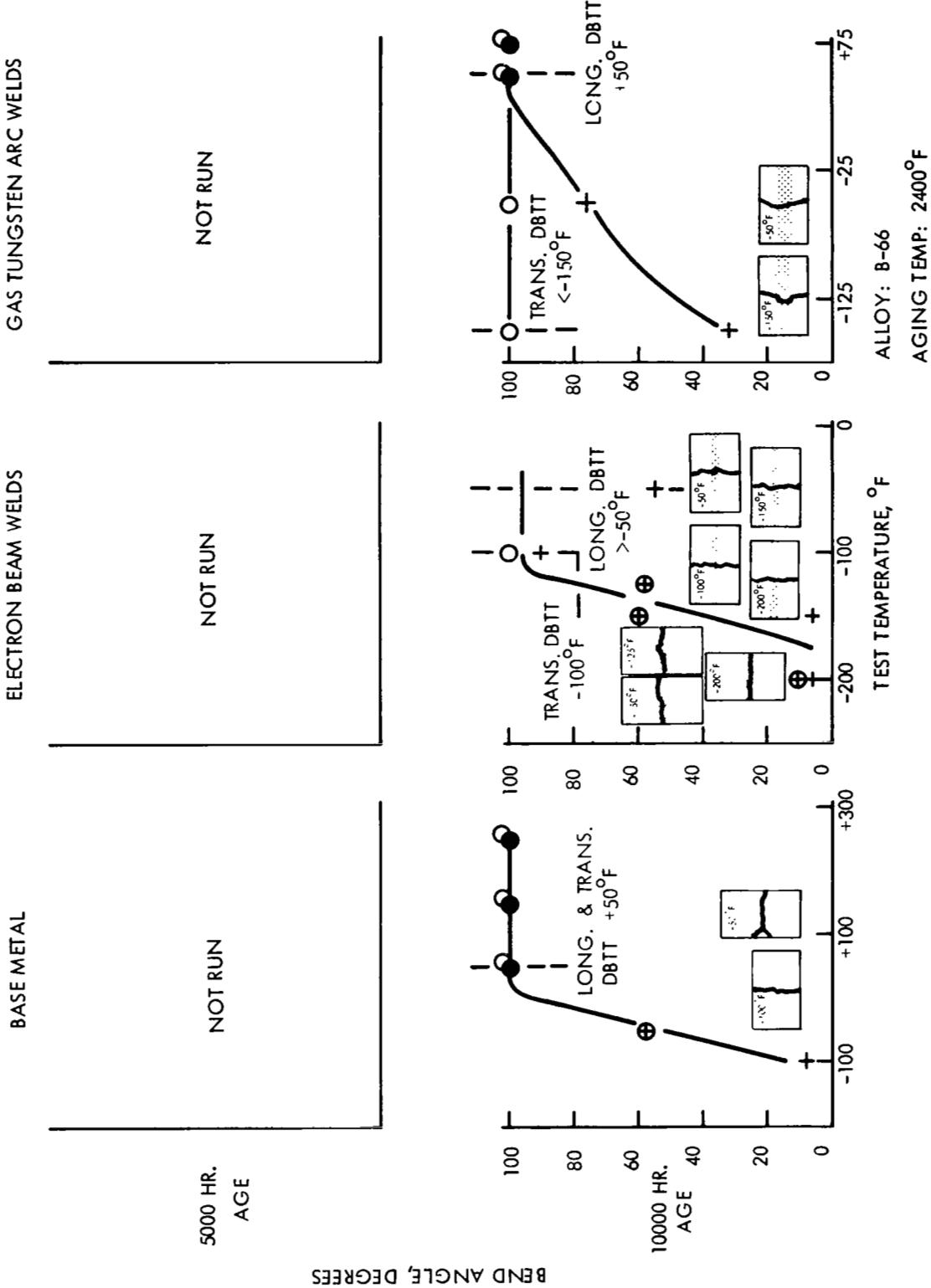


FIGURE A45 – Bend Test Results for B-66 Aged 5000 and 10,000 Hours at 2400°F (1t Bend Radius)

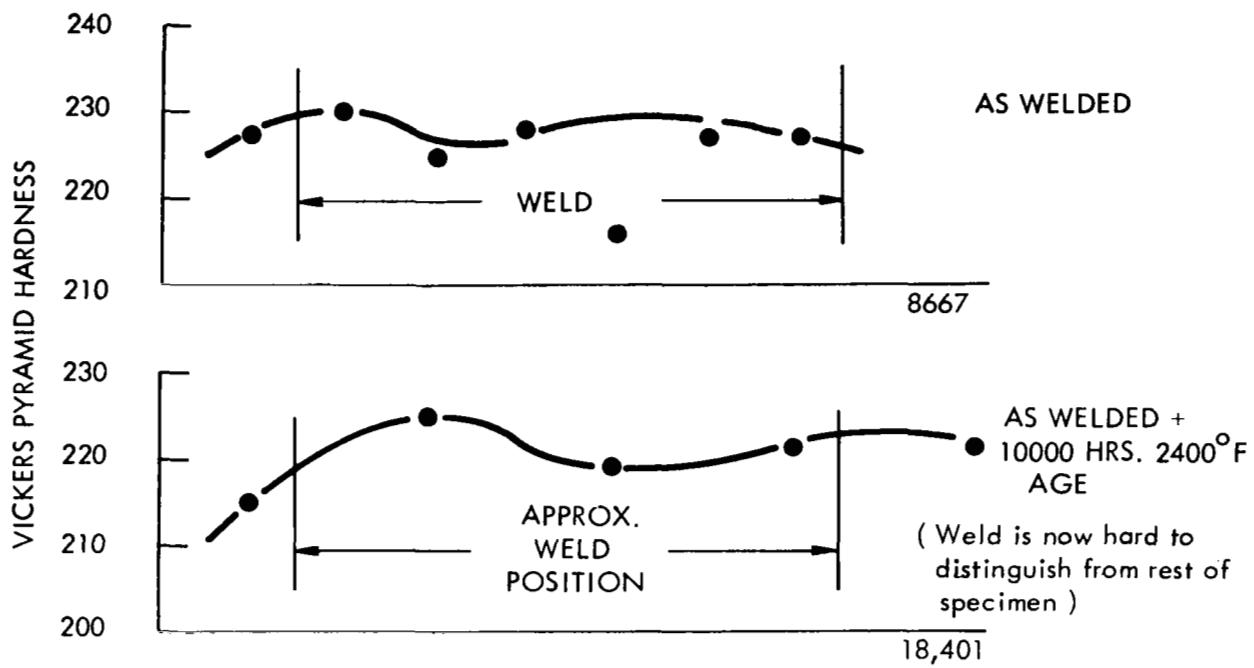
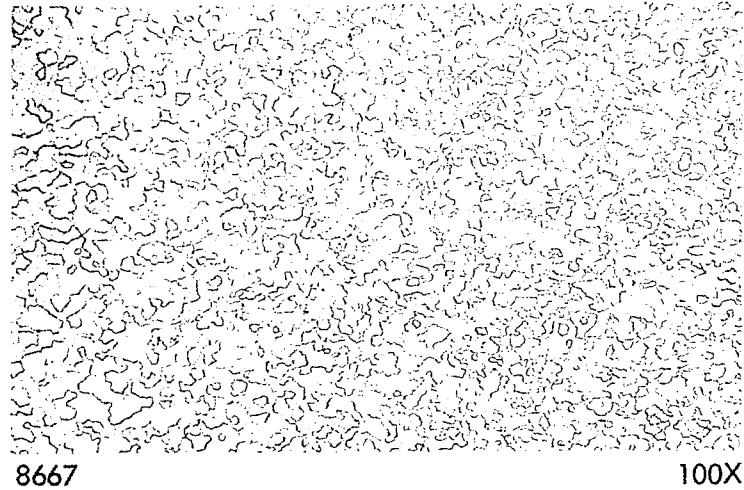
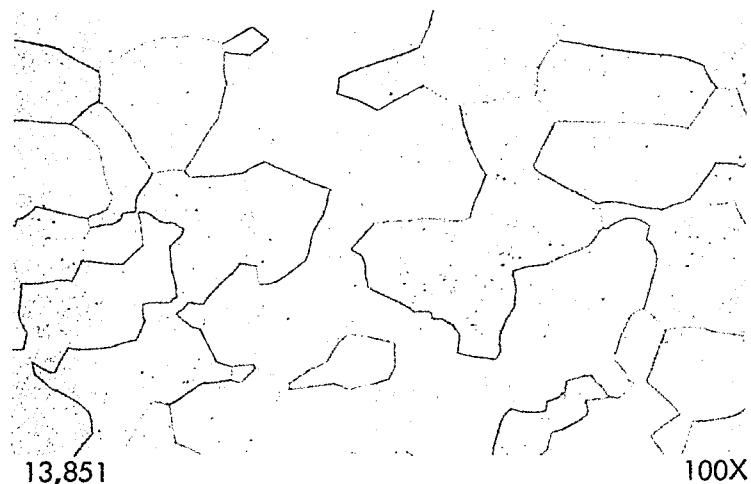


FIGURE A46 - Hardness Traverses for B-66 GTA Sheet Welds. Thermal History as Indicated. (10 Kg. Load on Vickers Hardness Tester.)

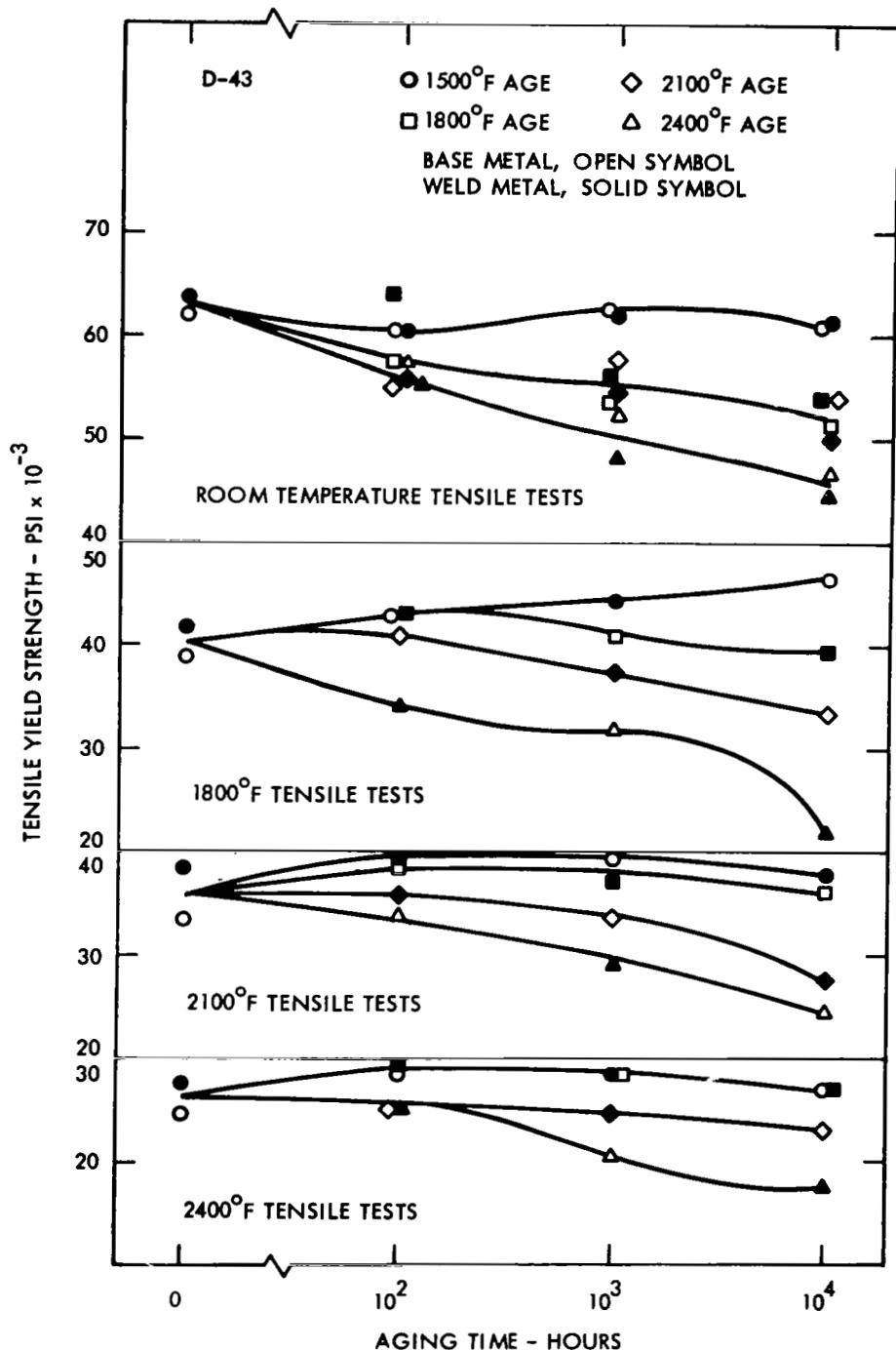


Base Metal of As Welded
GTA Weld



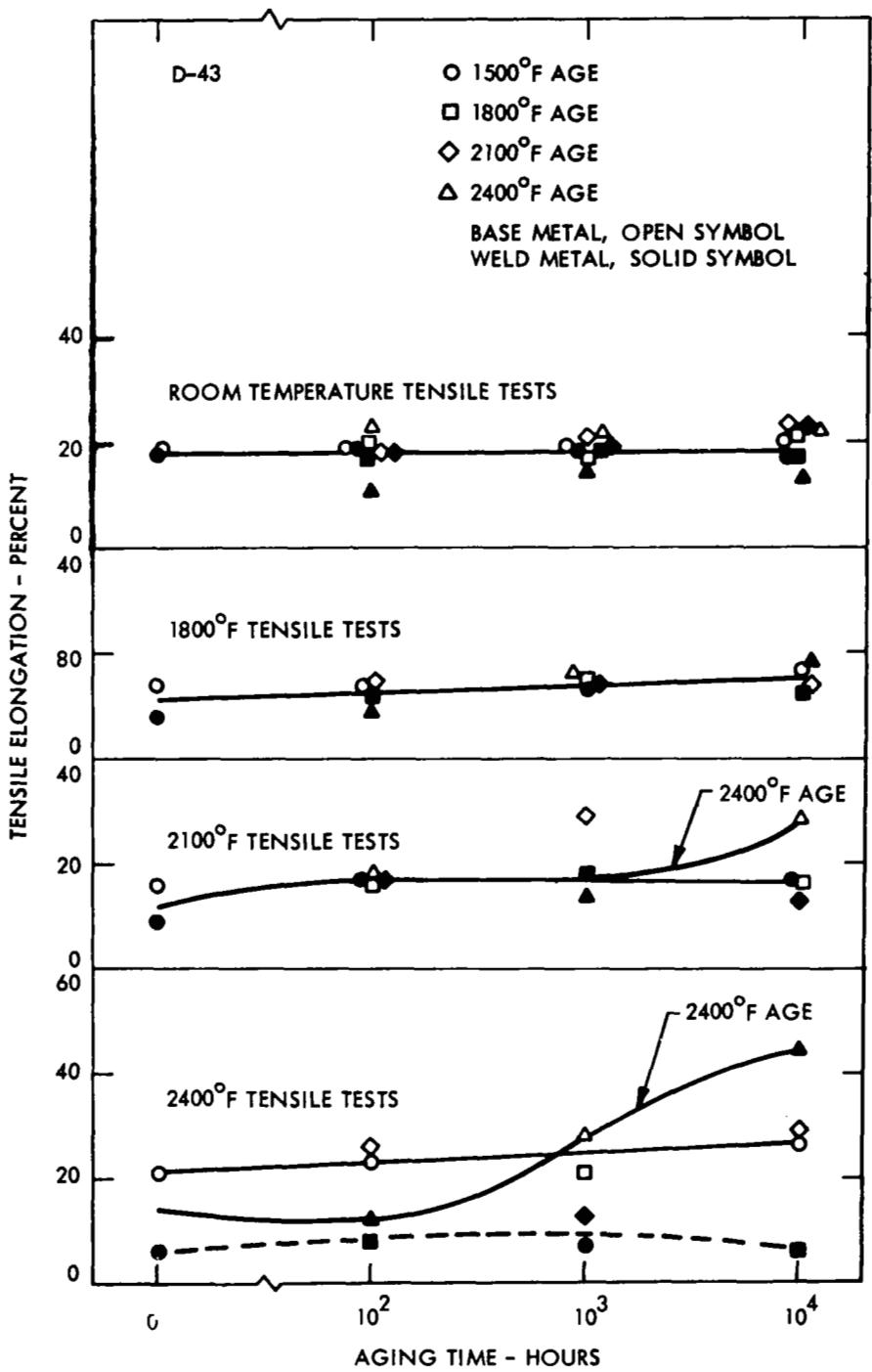
Base Metal Region of
GTA Weld Aged 1000 Hrs./2400° F
(Note massive grain growth
due to the aging exposure)

FIGURE A47 - Microstructures of B-66 GTA Weld Specimens.
Thermal History As Indicated.



NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hour at 2400°F Prior to Aging and Testing.

FIGURE A48 – Tensile Yield Strength of D-43 As A Function of Aging Parameters



NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hour At 2400°F Prior to Aging and Testing.

FIGURE A49 - Tensile Elongation of D-43 As A Function of Aging Parameters

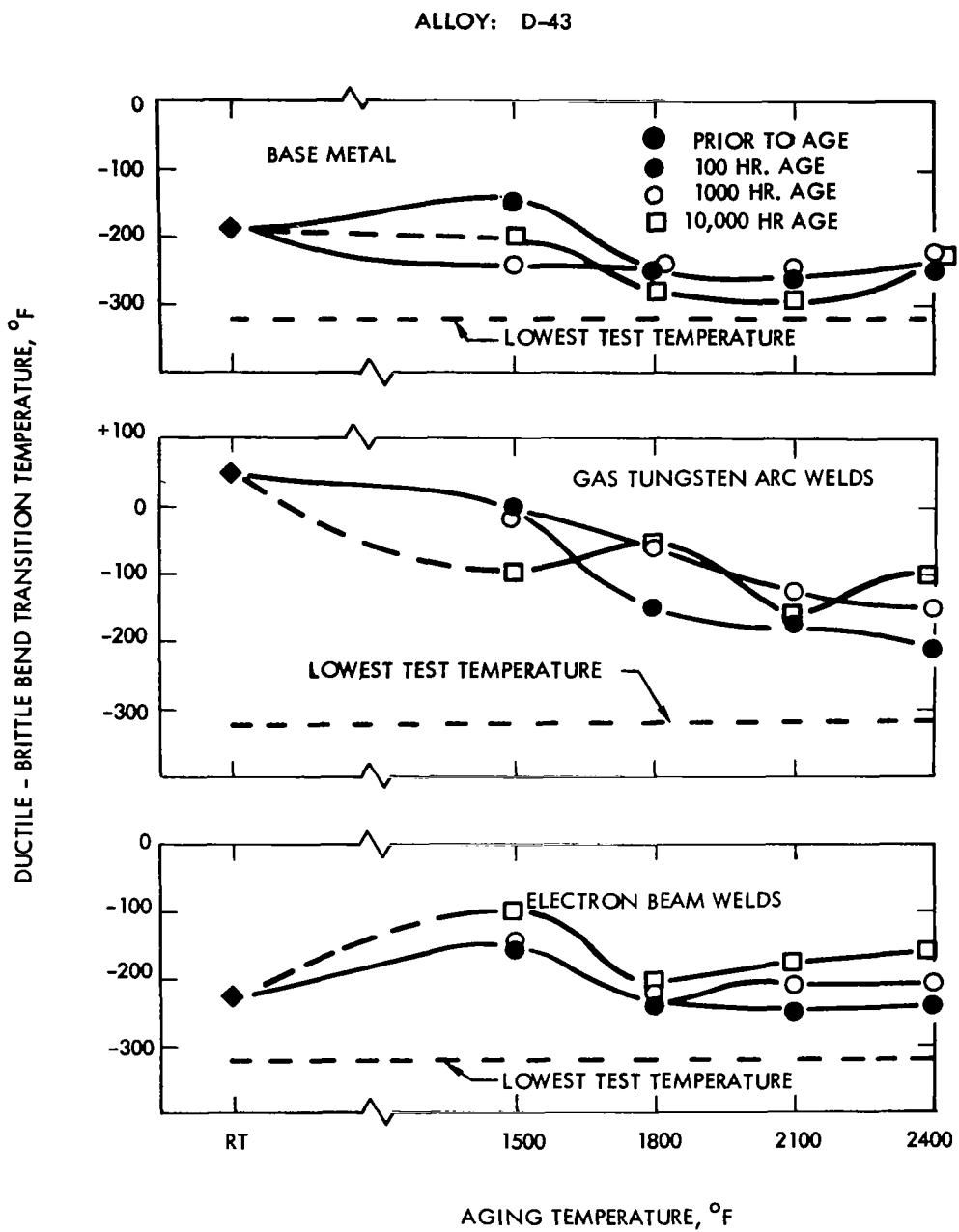
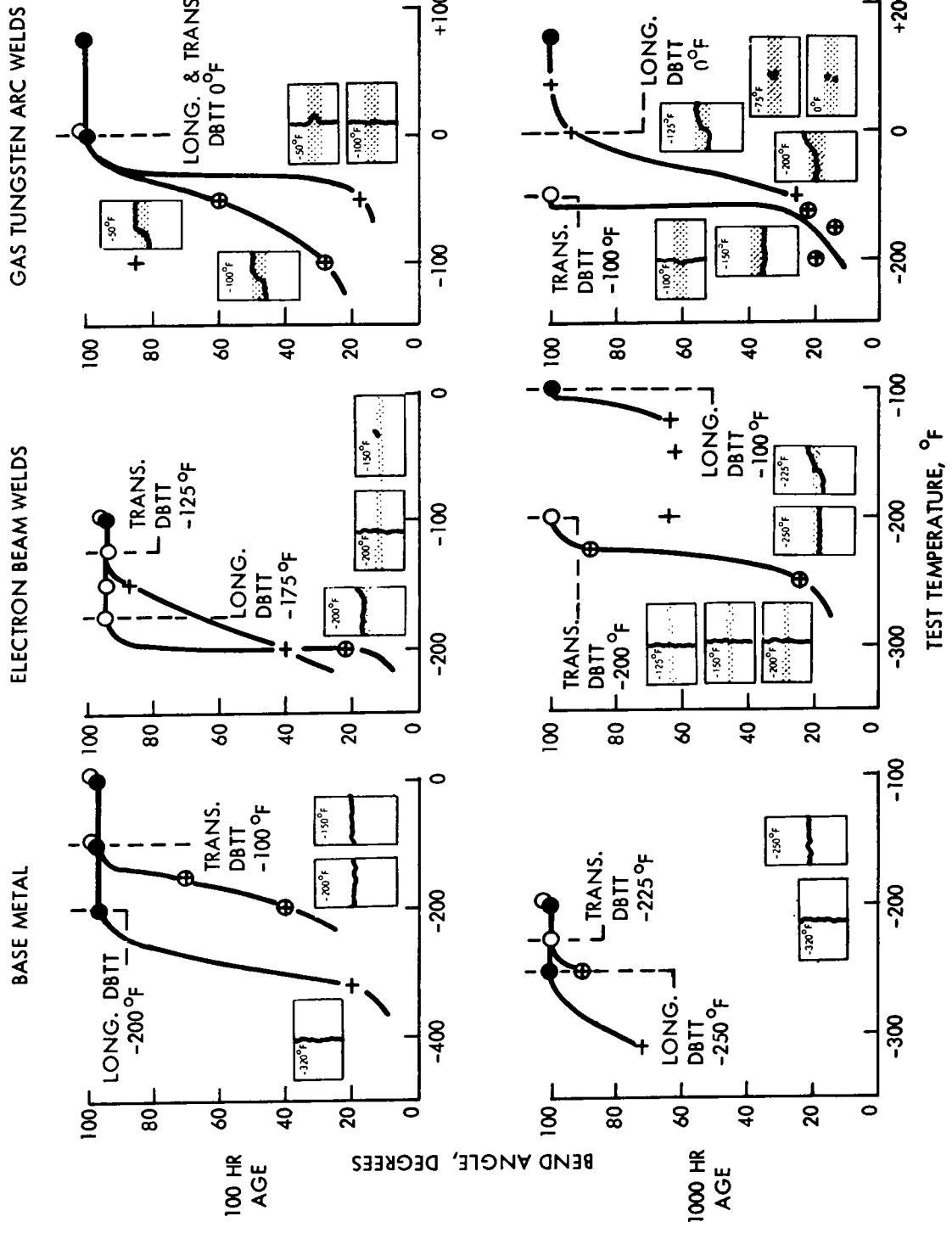


FIGURE A50 – Bend Ductile - Brittle Transition Temperature of D-43 As A Function Of Aging Parameters (1t Bend Radius)



BASE METAL
GAS TUNGSTEN ARC WELDS

ELECTRON BEAM WELDS

5000 HR.
AGE

NOT RUN

NOT RUN

BEND ANGLE, DEGREES

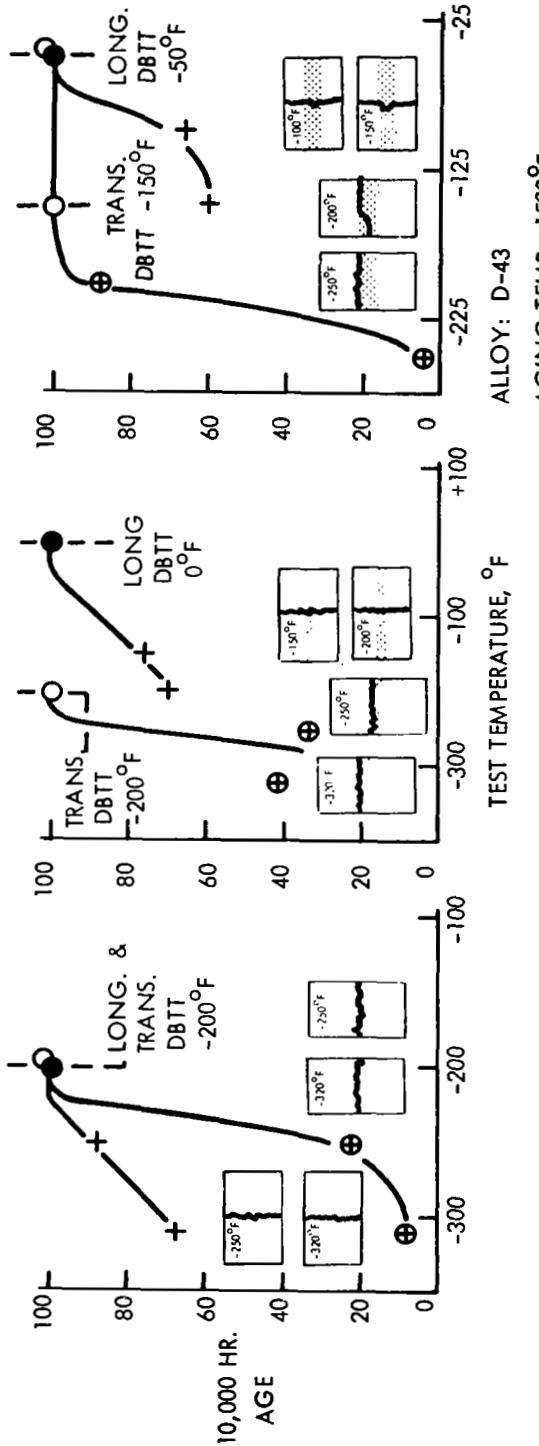


FIGURE A52 - Bend Test Results for D-43 Aged 5000 and 10,000 Hours at 1500°F
(1st Bend Radius)

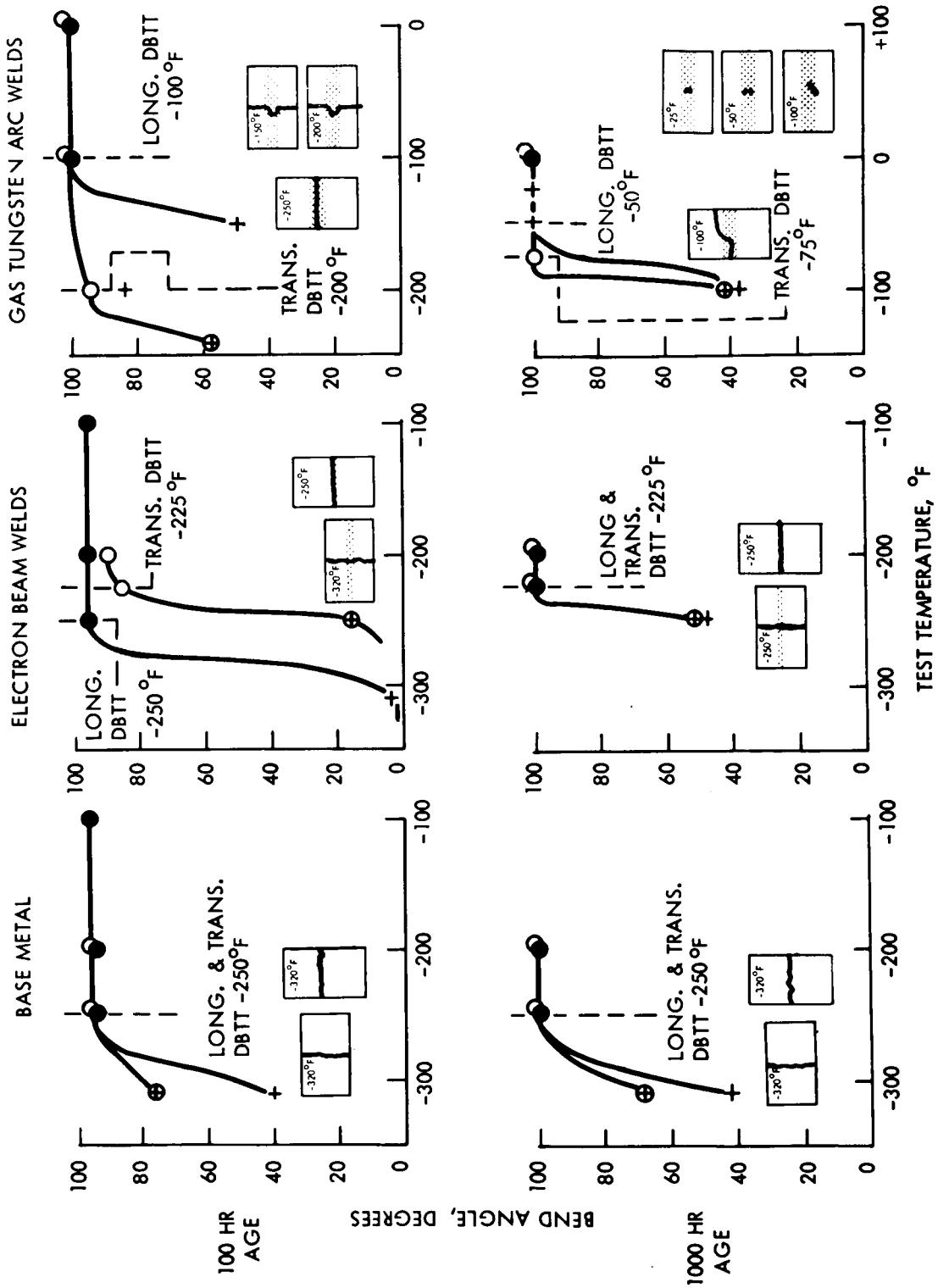
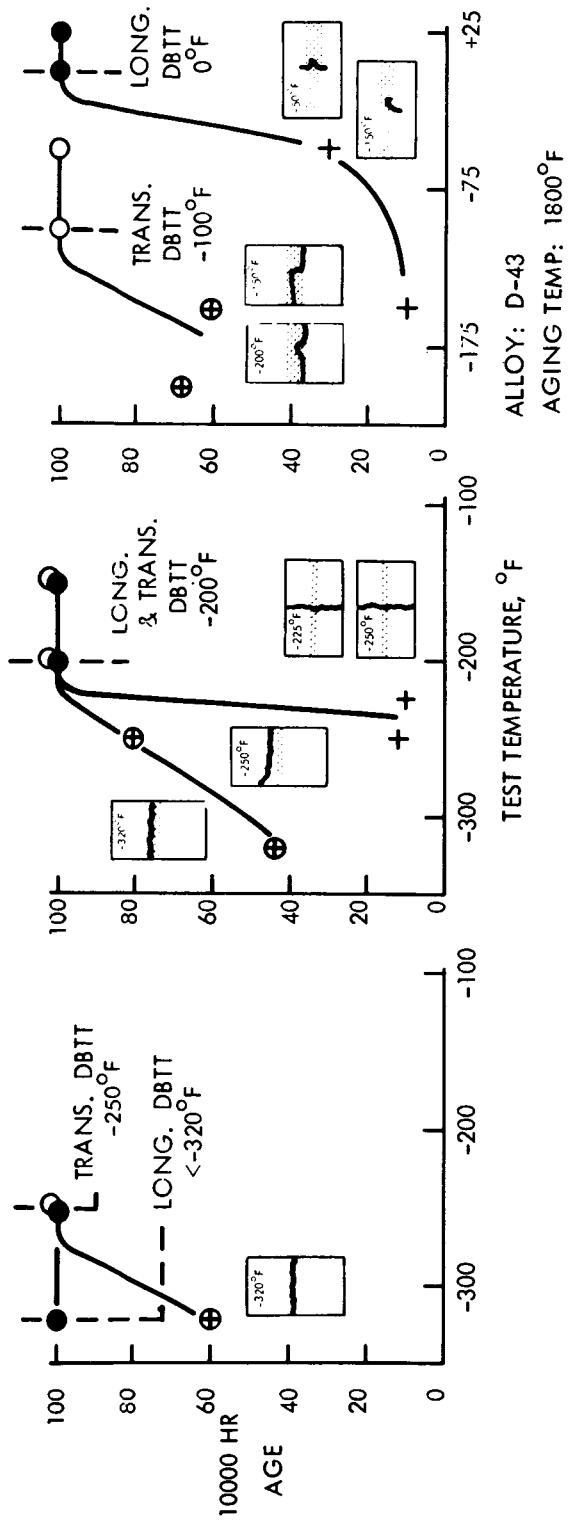
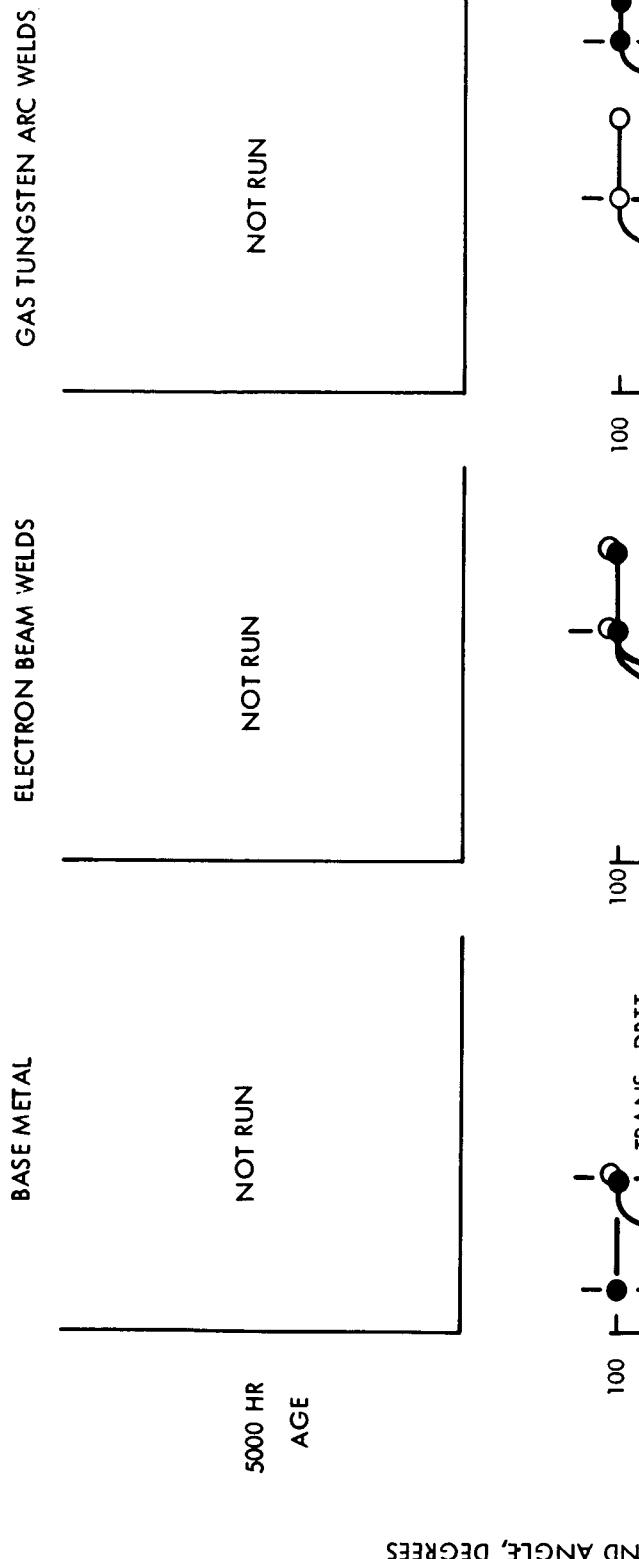


FIGURE A53 – Bend Test Results for D-43 Aged 100 and 1000 Hours at 1800°F (1" Bend Radius)



**FIGURE A54 - Bend Test Results for D-43 Aged 5000 and 10,000 Hours at 1800°F
(1 ft Bend Radius)**

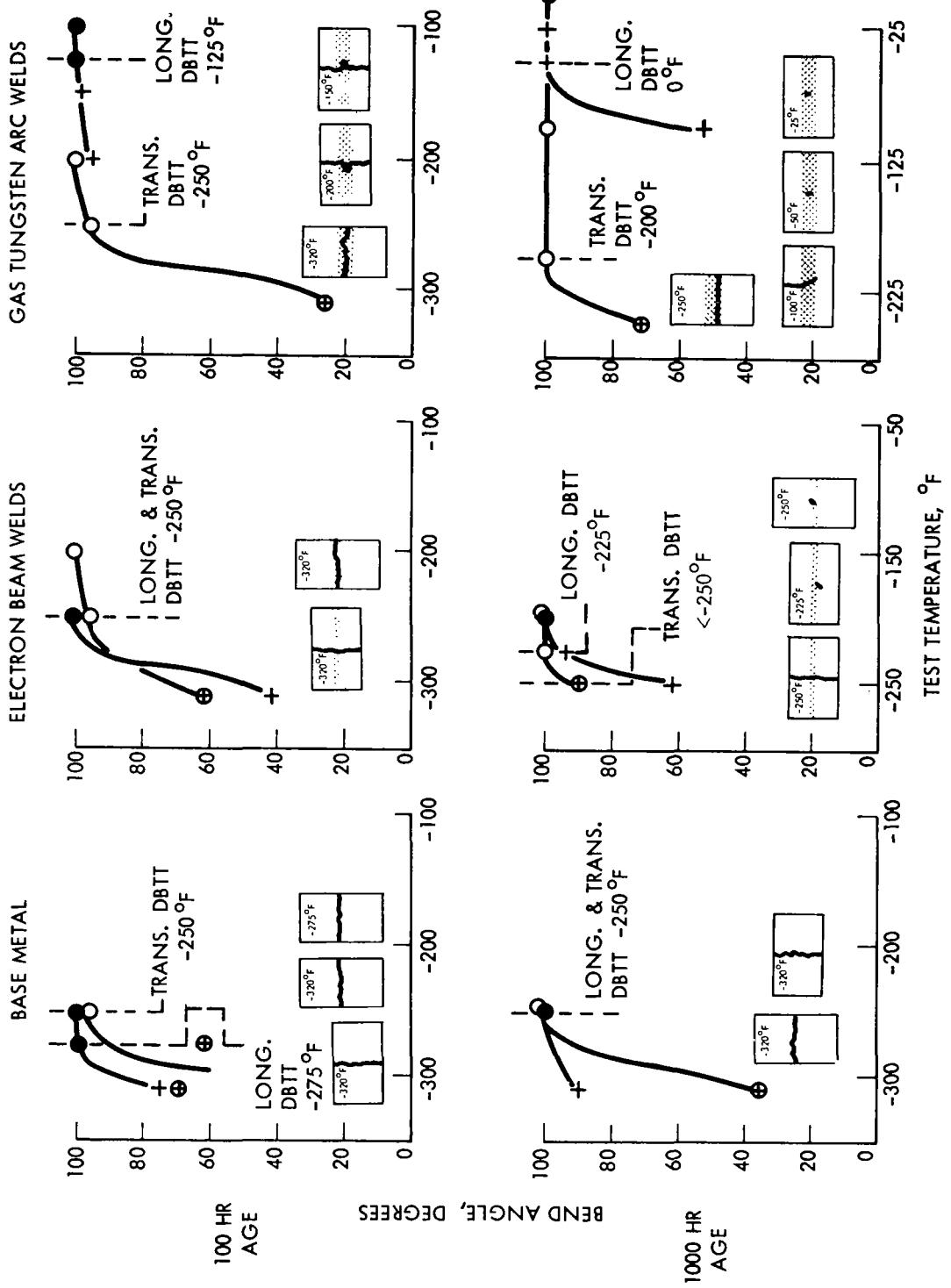


FIGURE A55 - Bend Test Results for D-43 Aged 100 and 1000 Hours at 2100°F
(1 ft Bend Radius)

BASE METAL

ELECTRON BEAM WELDS

GAS TUNGSTEN ARC WELDS

5000 HR AGE

NOT RUN

NOT RUN

NOT RUN

BEND ANGL E, DEGREES

109

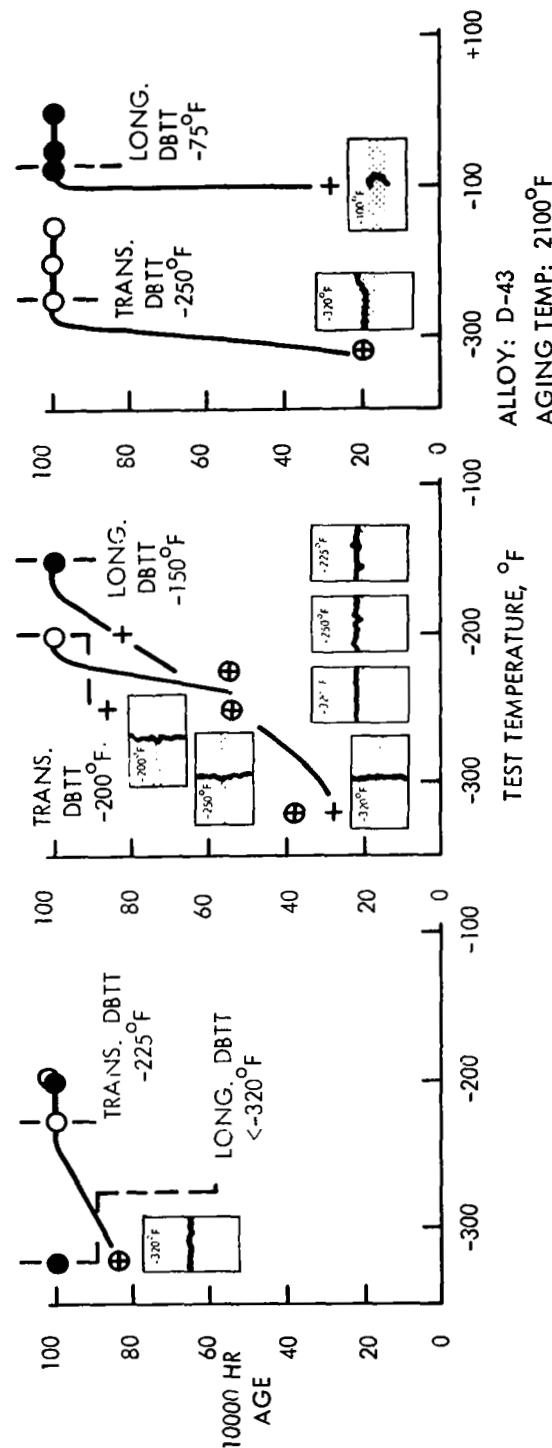


FIGURE A56 - Bend Test Results for D-43 Aged 500 and 10,000 Hours at 2100°F
(1st Bend Radius)

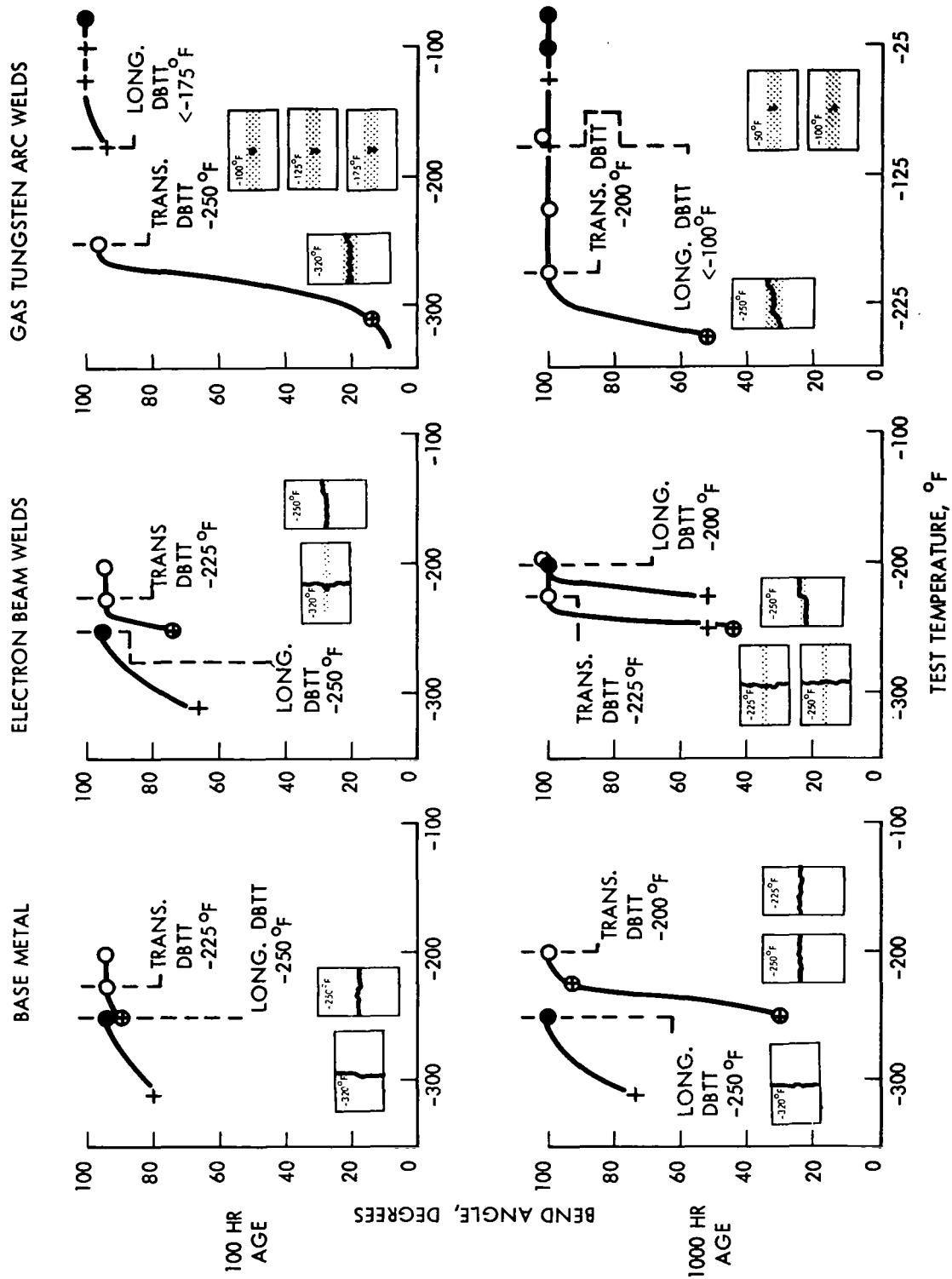


FIGURE A57 – Bend Test Results for D-43 Aged 100 and 1000 Hours at 2400°F
(1^{1/2} Bend Radius)

ALLOY: D-43
AGING TEMP: 2400°F

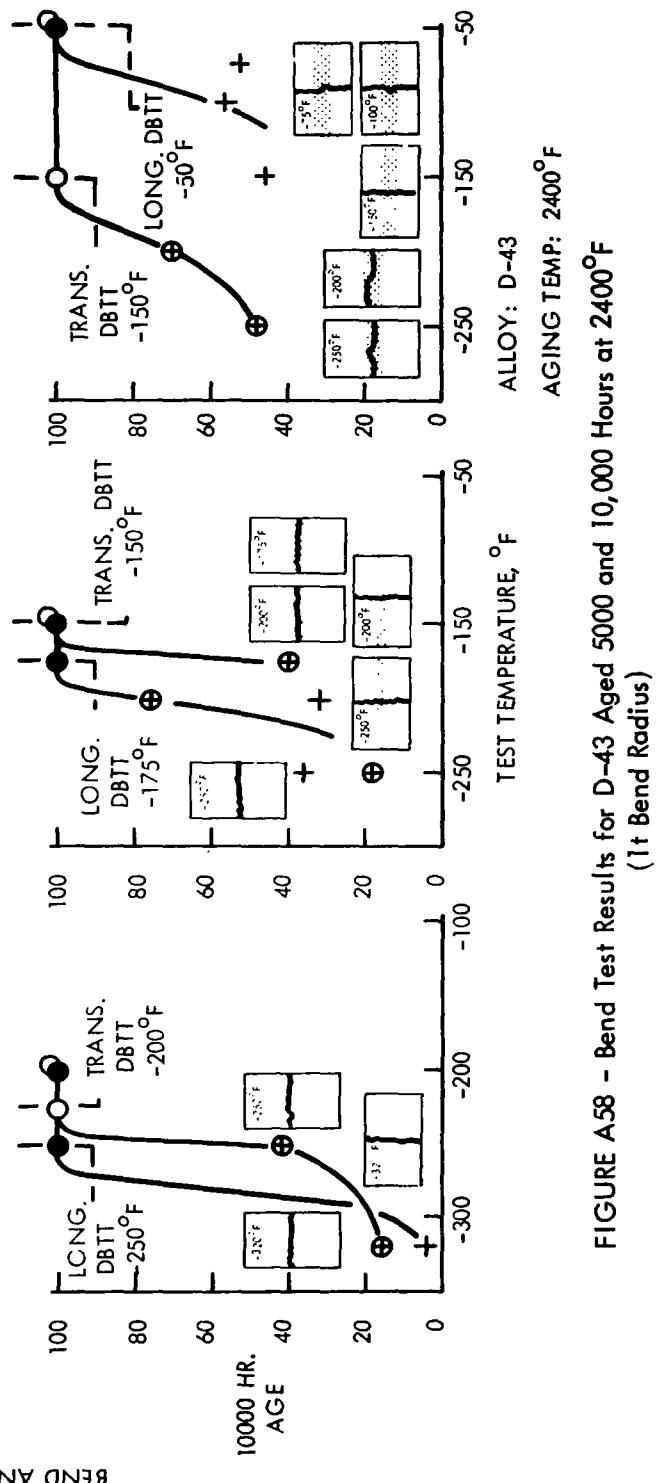
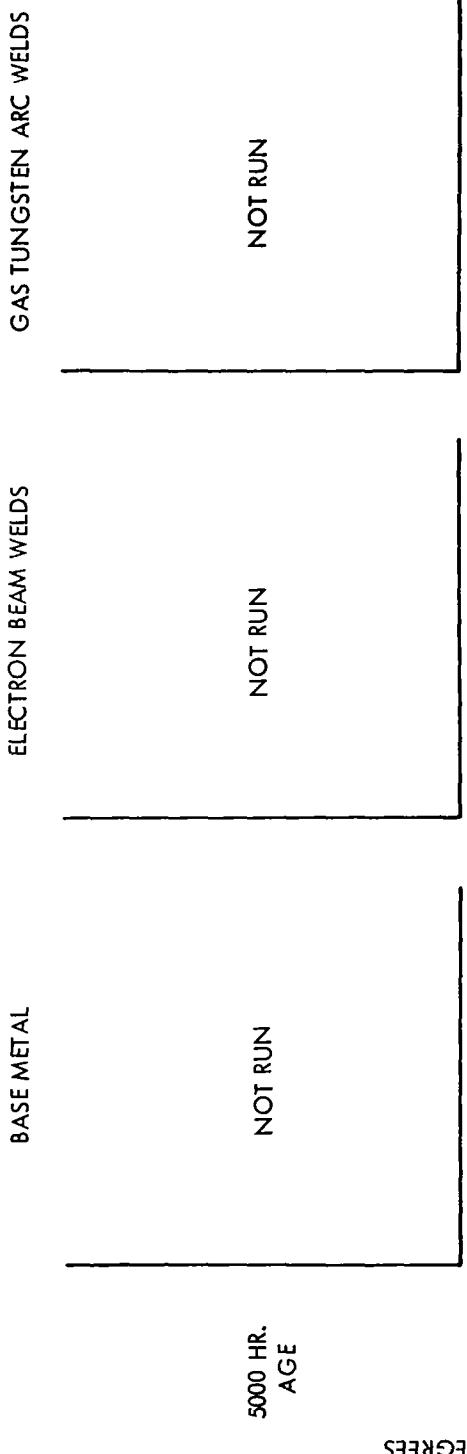


FIGURE A58 - Bend Test Results for D-43 Aged 5000 and 10,000 Hours at 2400°F (1t Bend Radius)

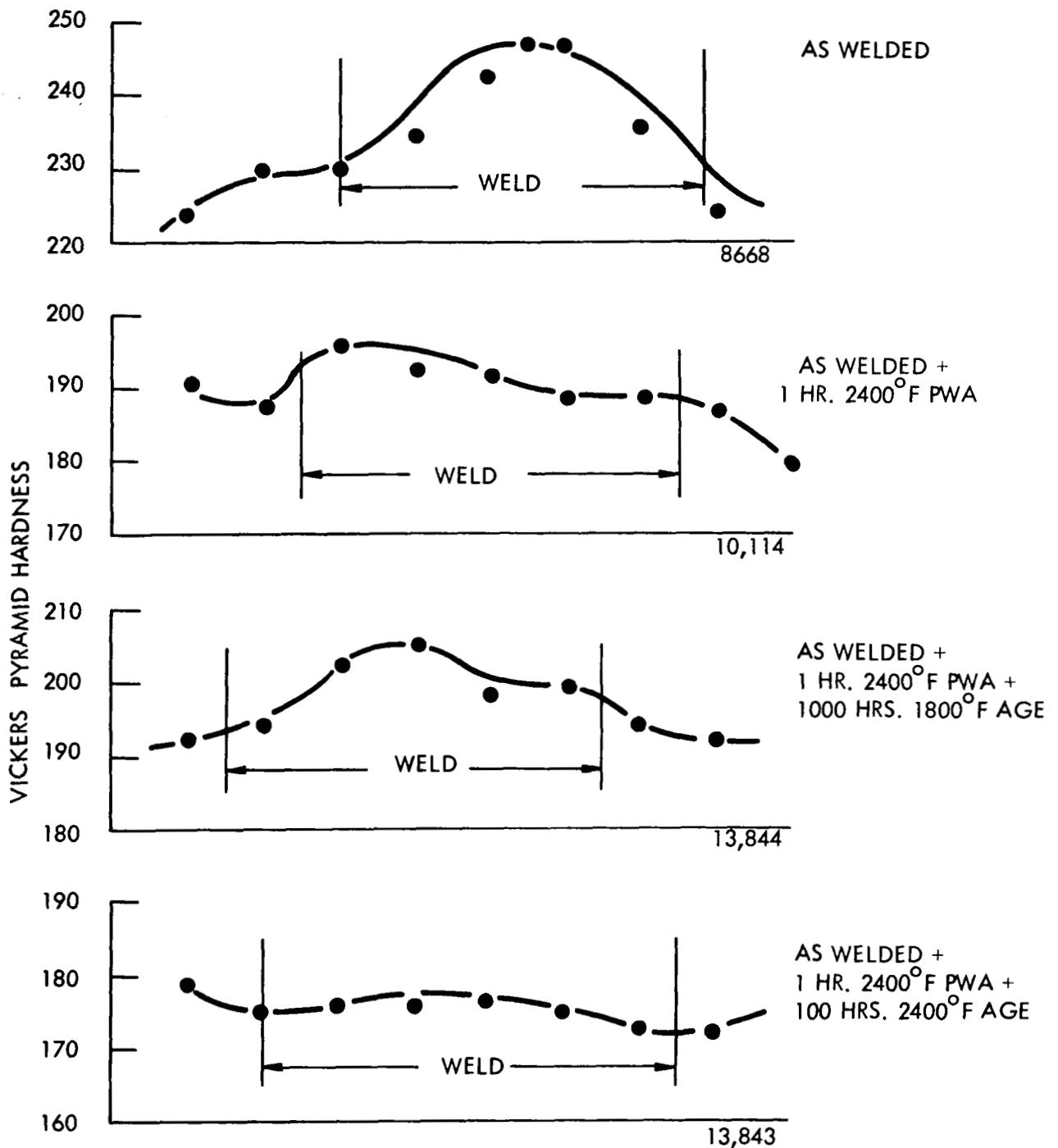


FIGURE A59 - Hardness Traverses for D-43 GTA Sheet Welds. Thermal History As Indicated. (10 Kg. Load on Vickers Hardness Tester.)

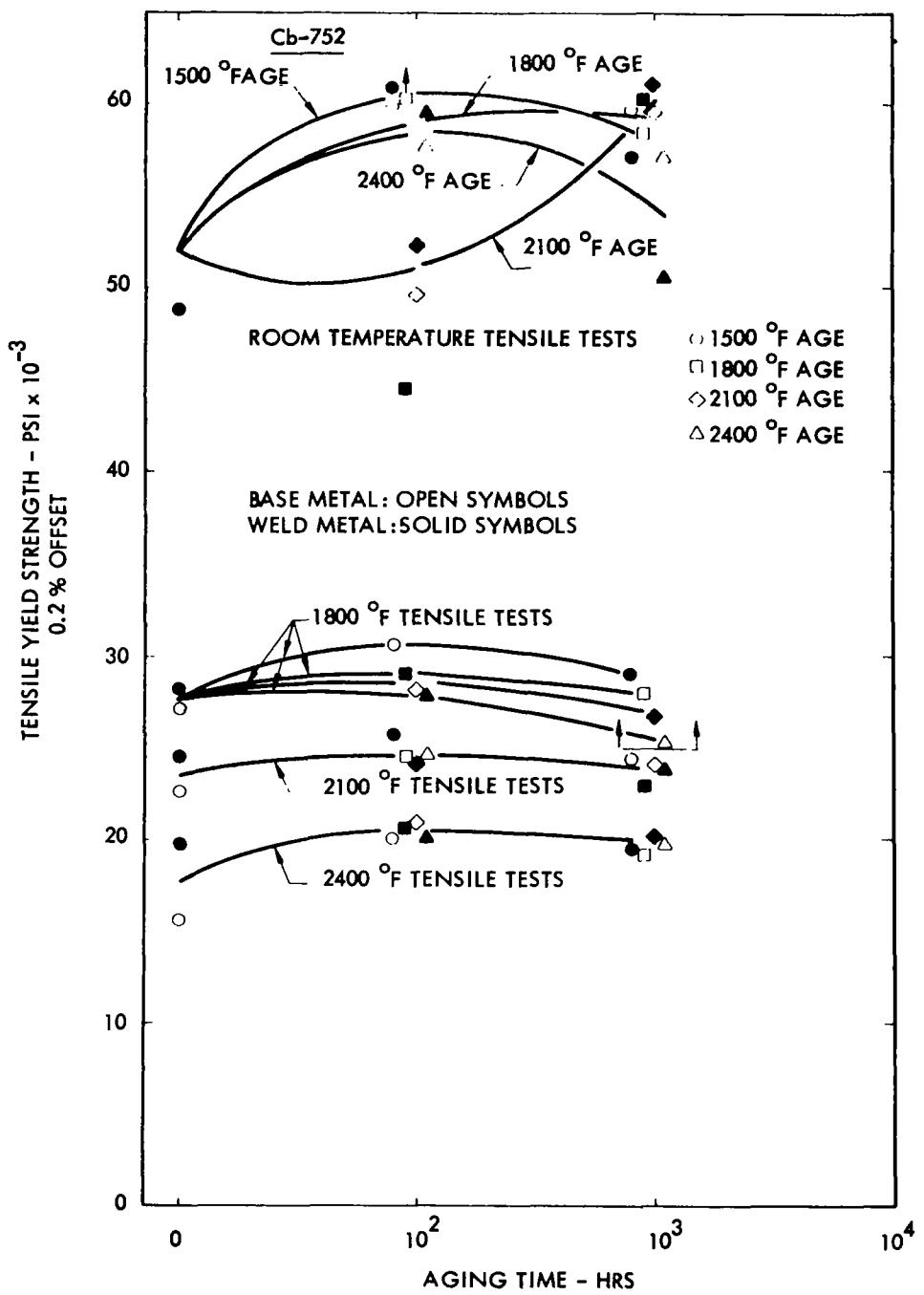
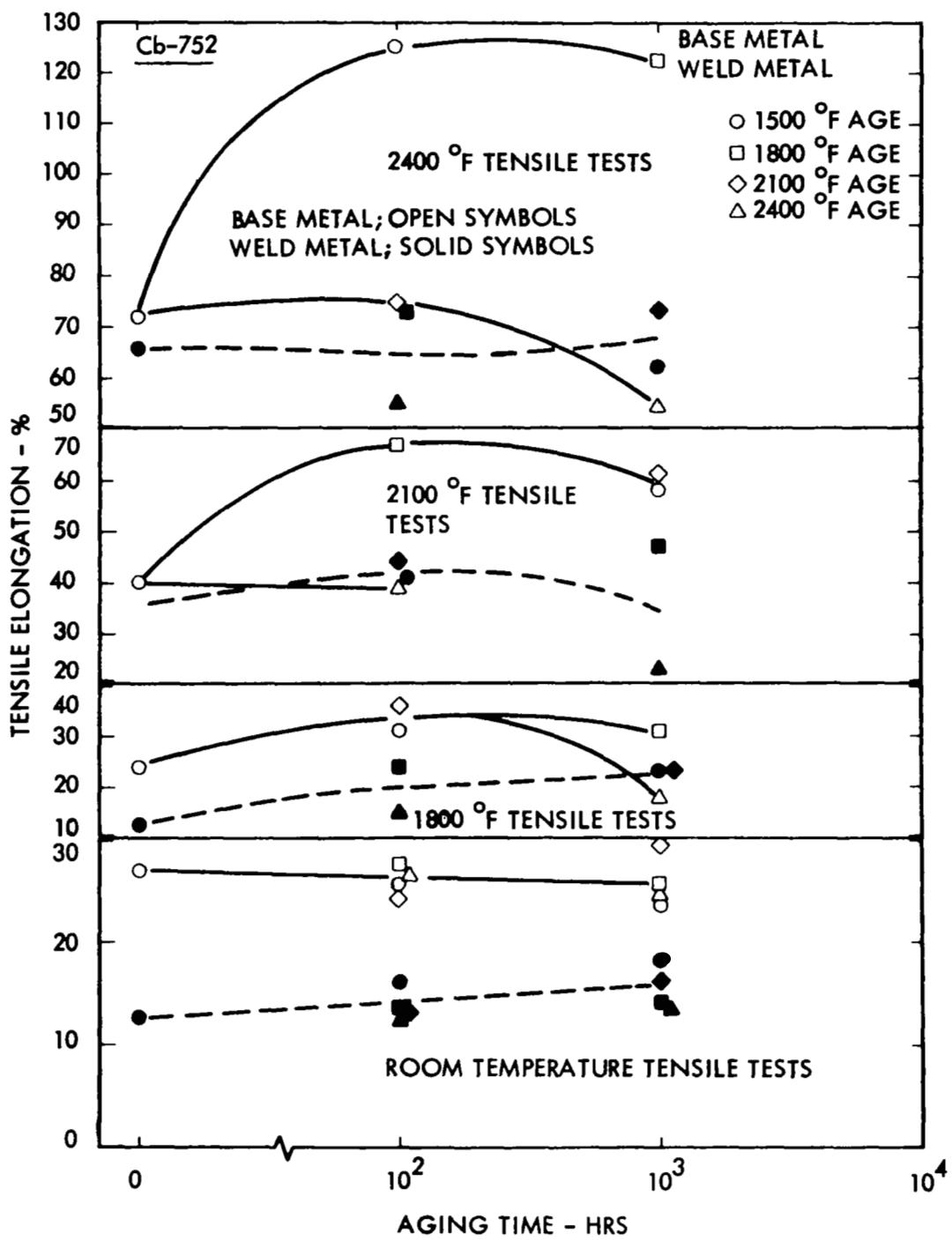


FIGURE A60 – Tensile Yield Strength of Cb-752 as a Function of Aging Parameters



NOTE: Optimum Weld Parameters, All Samples Annealed
1 Hour at 2200°F Prior to Aging and Testing.

FIGURE A61 - Tensile Elongation of Cb-752 as a Function of Aging Parameters.

ALLOY: Cb-752

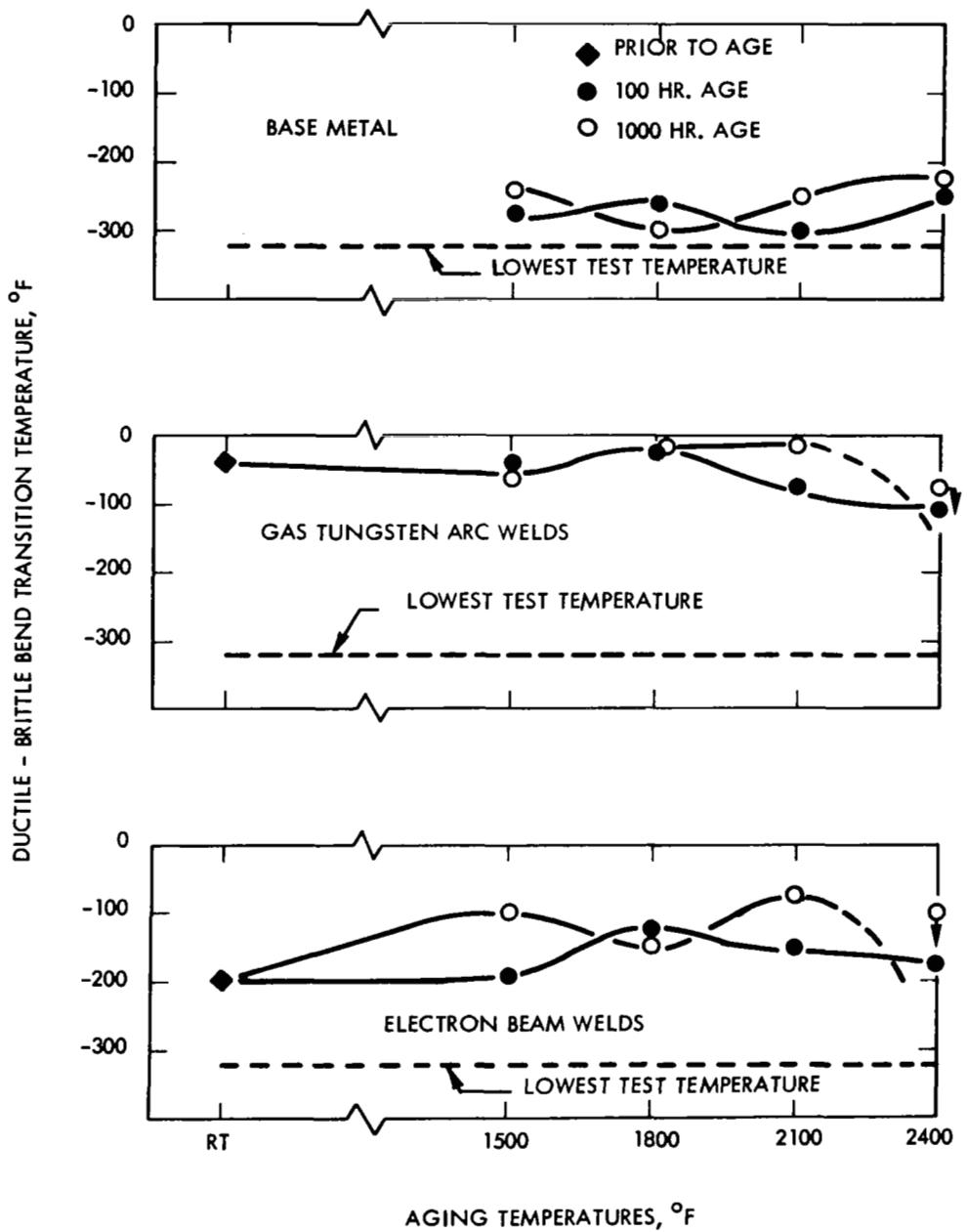
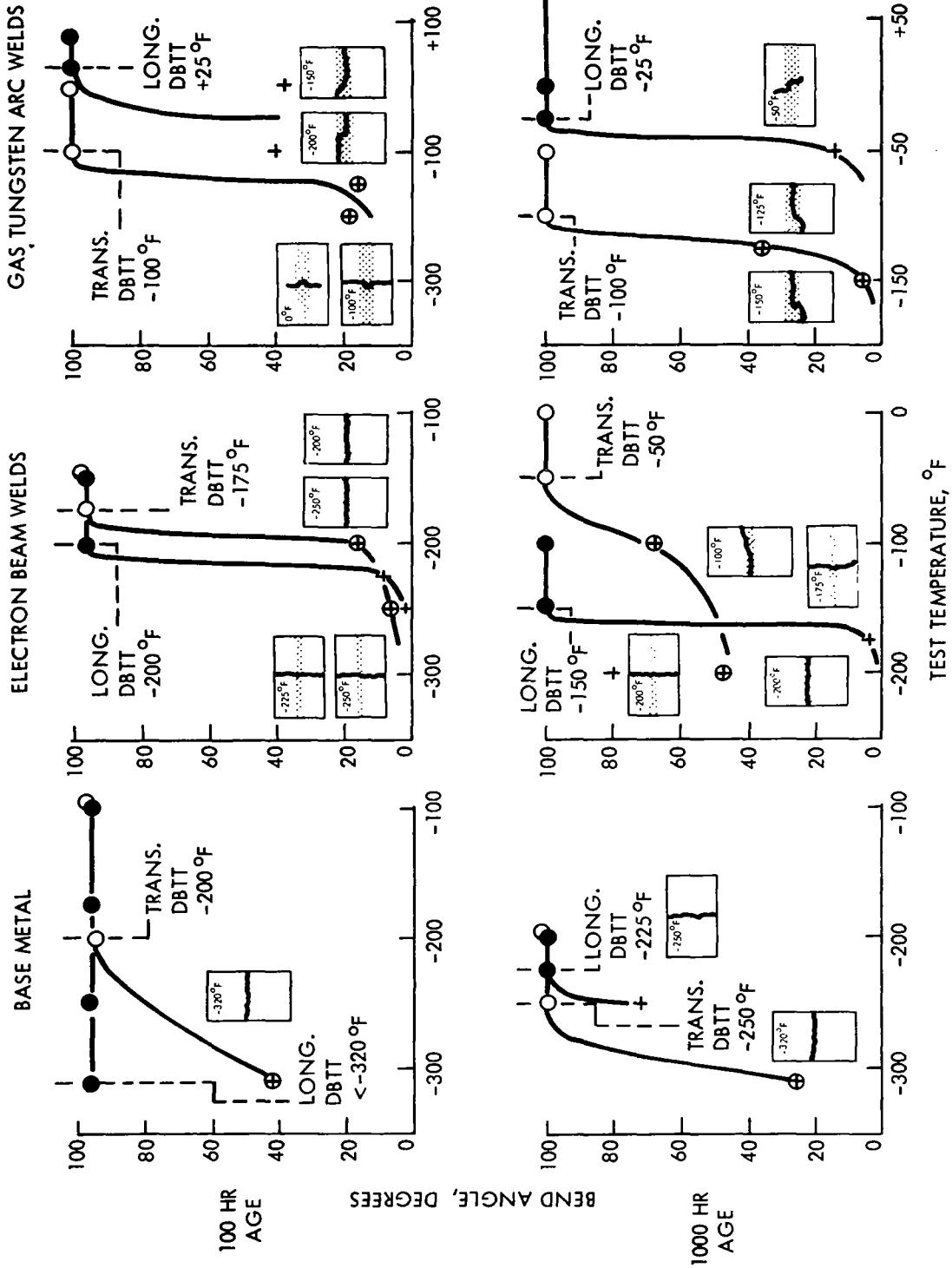


FIGURE A62 - Bend Ductile - Brittle Transition Temperature of Cb-752 as a Function of Aging Parameters (1t Bend Radius)



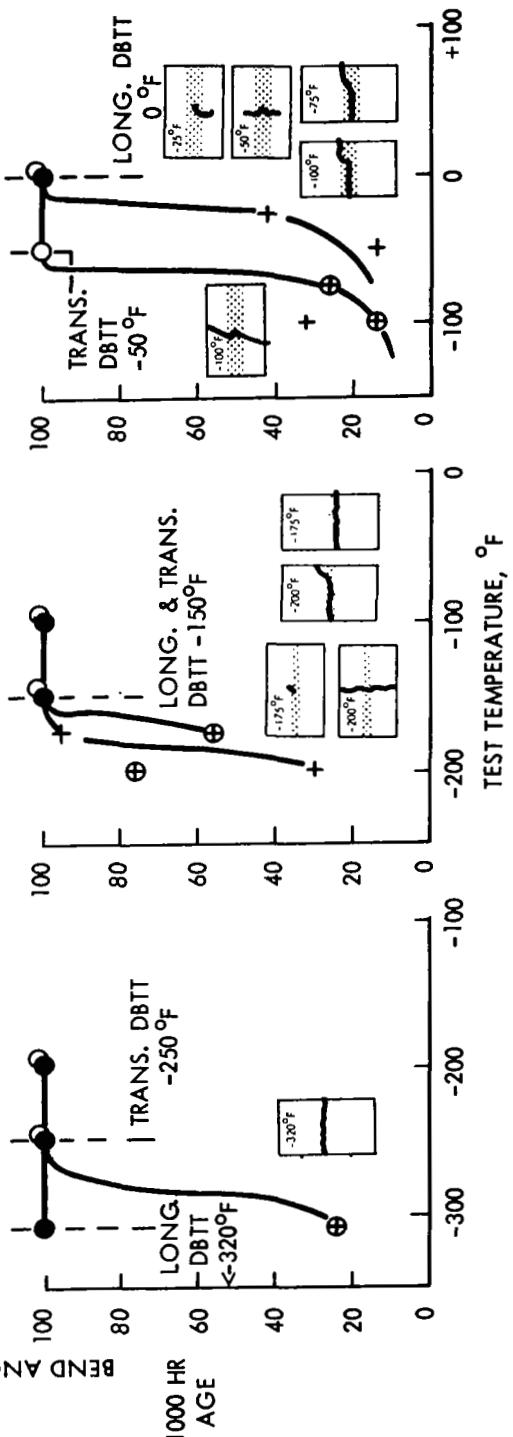
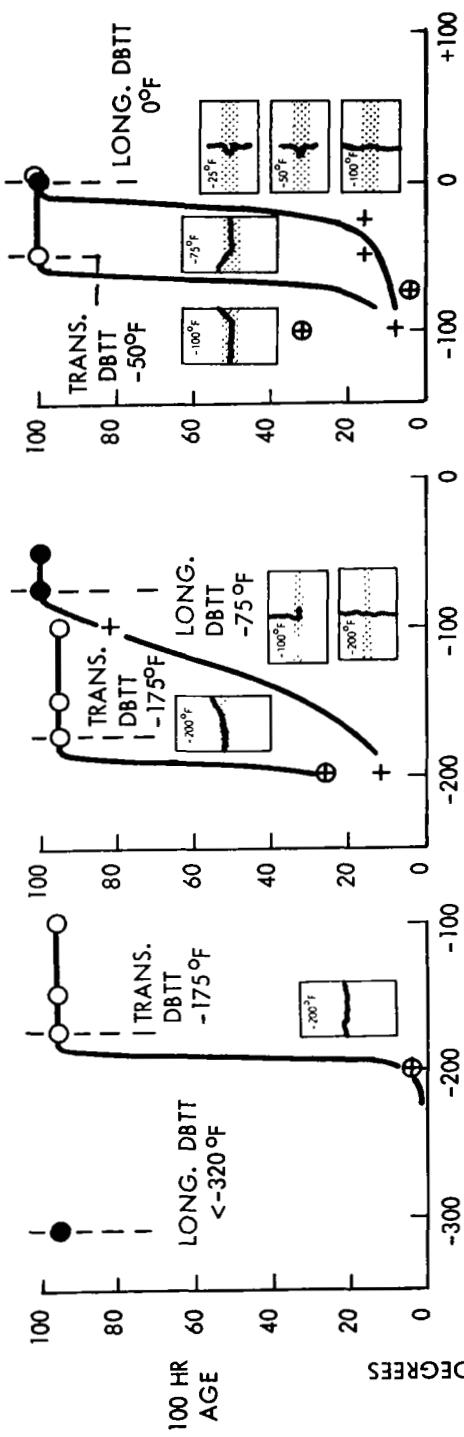
ALLOY: Cb-752
AGING TEMP: 1500 °F

FIGURE A63 – Bend Test Results for Cb-752 Aged 100 and 1000 Hours at 1500°F
(1† Bend Radius)

GAS TUNGSTEN ARC WELDS

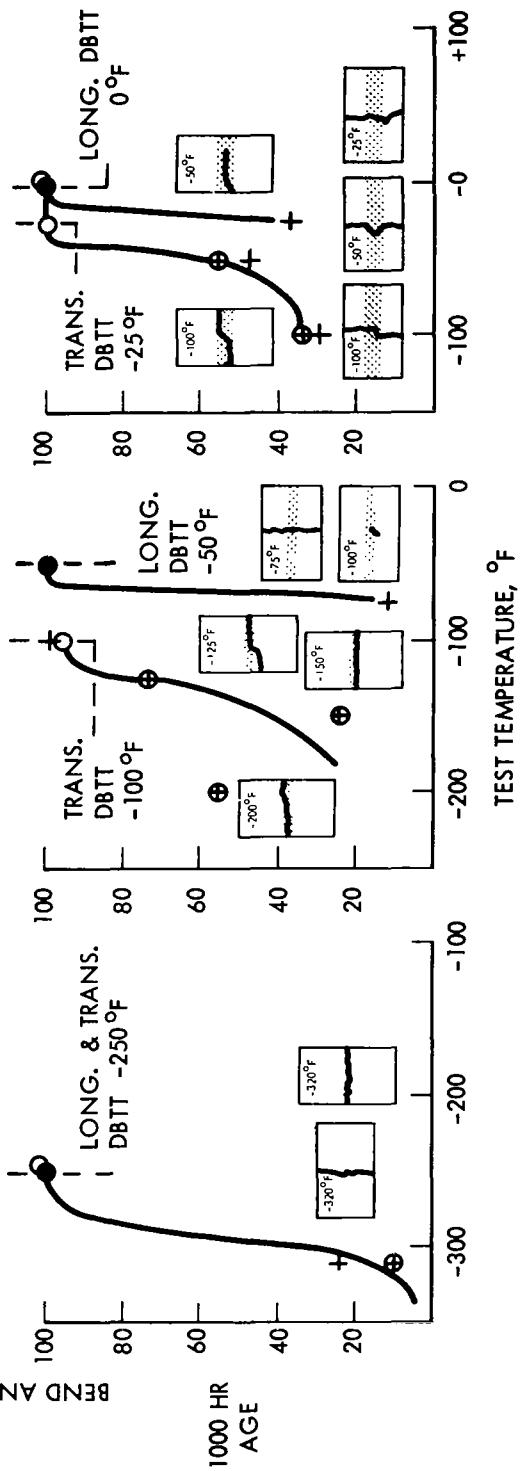
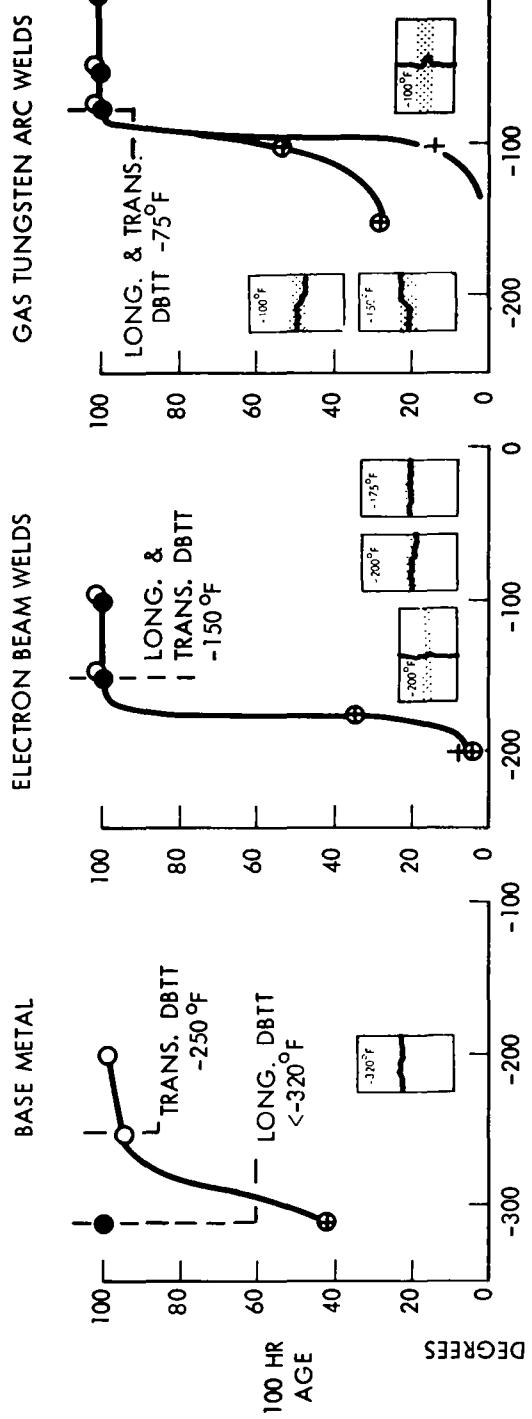
ELECTRON BEAM WELDS

BASE METAL



ALLOY: Cb-752
AGING TEMP: 1800°F

FIGURE A64 - Bend Test Results for Cb-752 Aged 100 and 1000 Hours at 1800°F
(1st Bend Radius)



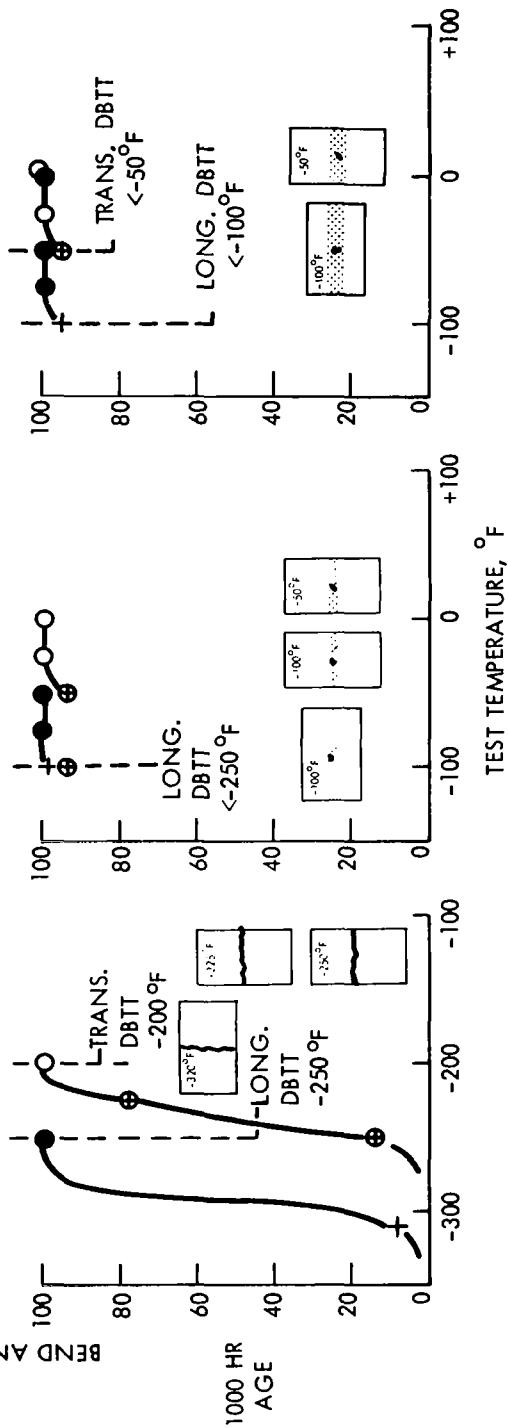
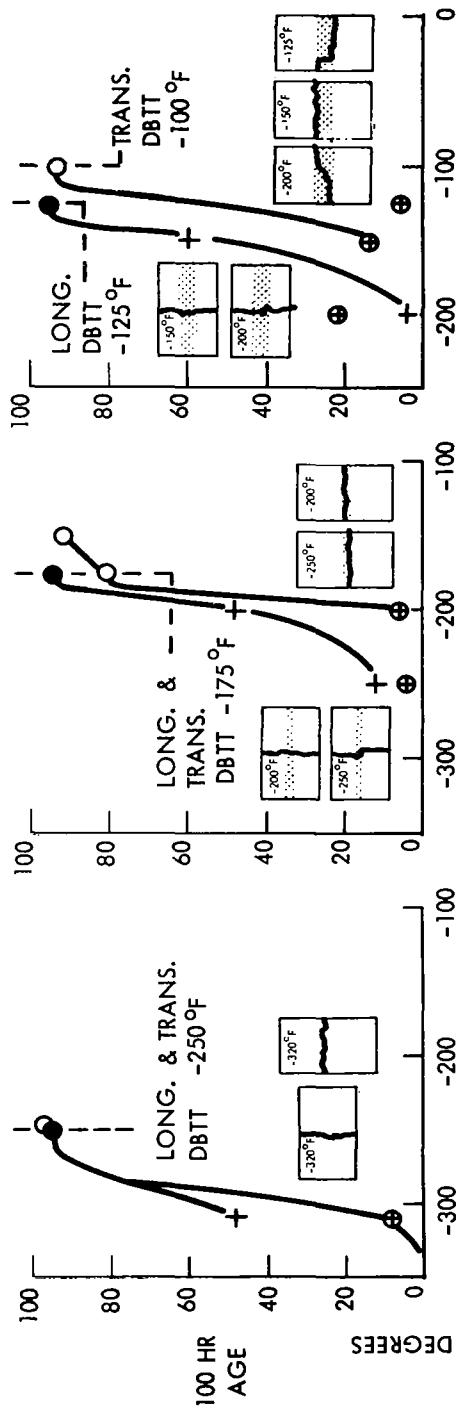
ALLOY: Cb - 752
AGING TEMP: 2100 °F

**FIGURE A65 - Bend Test Results for Cb-752 Aged 100 and 1000 Hours at 2100°F
(1 ft Bend Radius)**

GAS TUNGSTEN ARC WELDS

ELECTRON BEAM WELDS

BASE METAL



ALLOY: Cb-752
AGING TEMP: 2400 °F

FIGURE A66 – Bend Test Results for Cb-752 Aged 100 and 1000 Hours at 2400 °F
(1st Bend Radius)

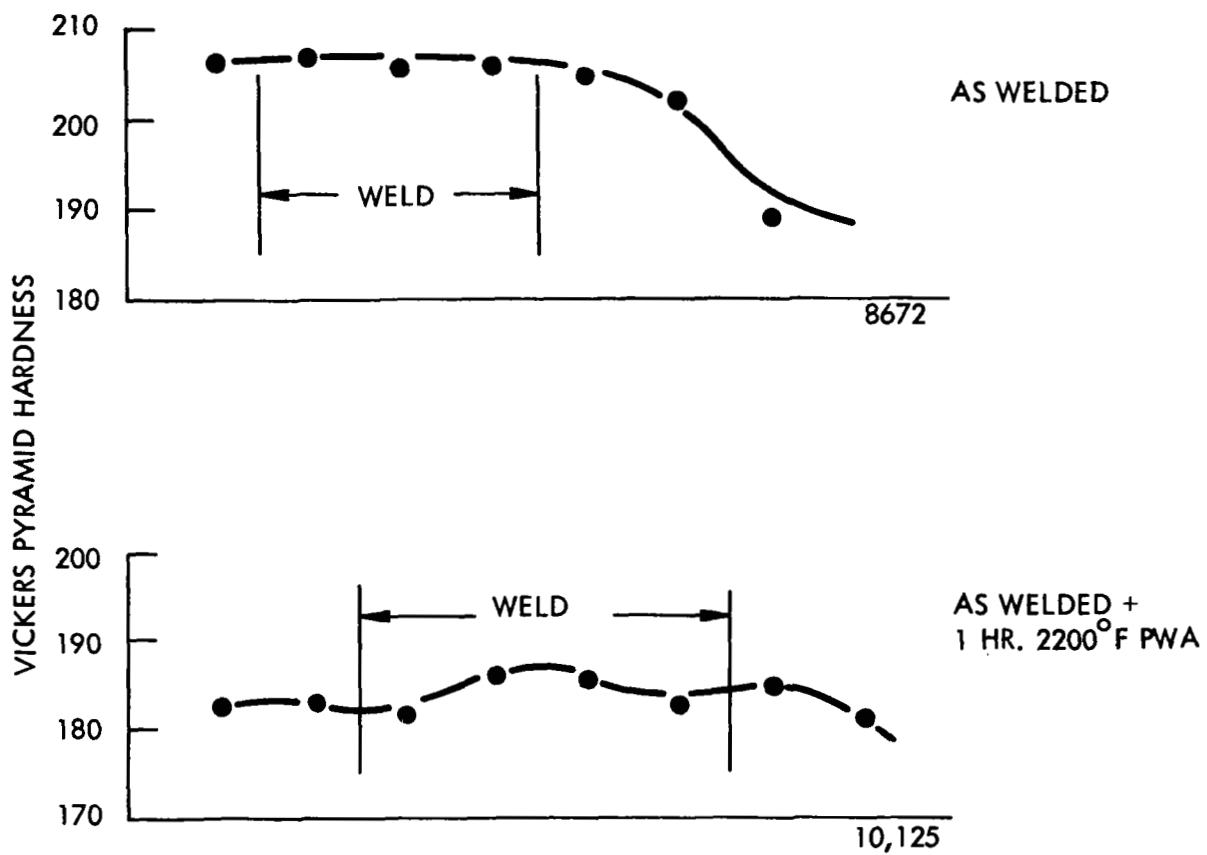
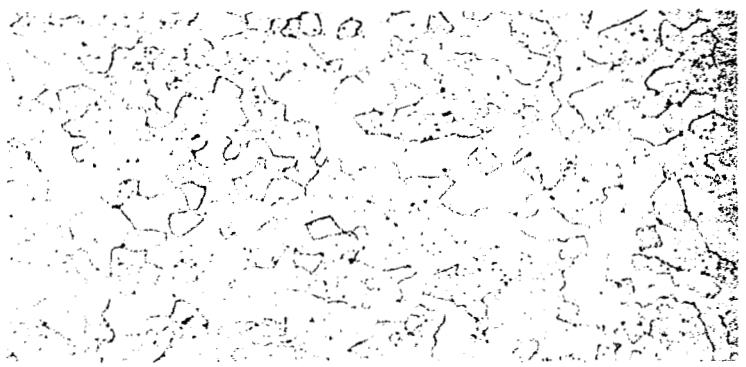
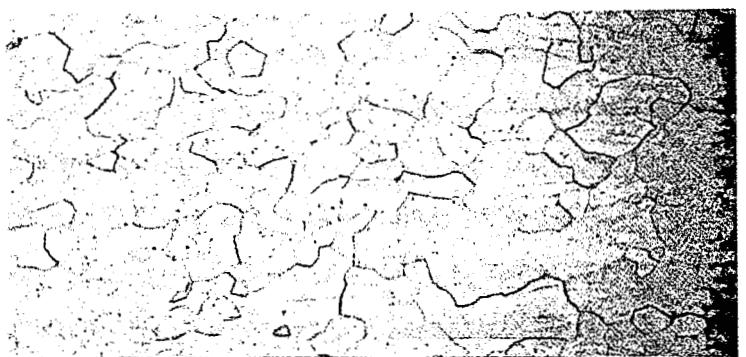


FIGURE A67 - Hardness Traverses for Cb-752 GTA Sheet Welds. Thermal History as Indicated. (10 Kg. Load on Vickers Hardness Tester.)



10,125 Base Metal of GTA Weld Specimen 400X
Following 1 Hr.-2200°F PWA

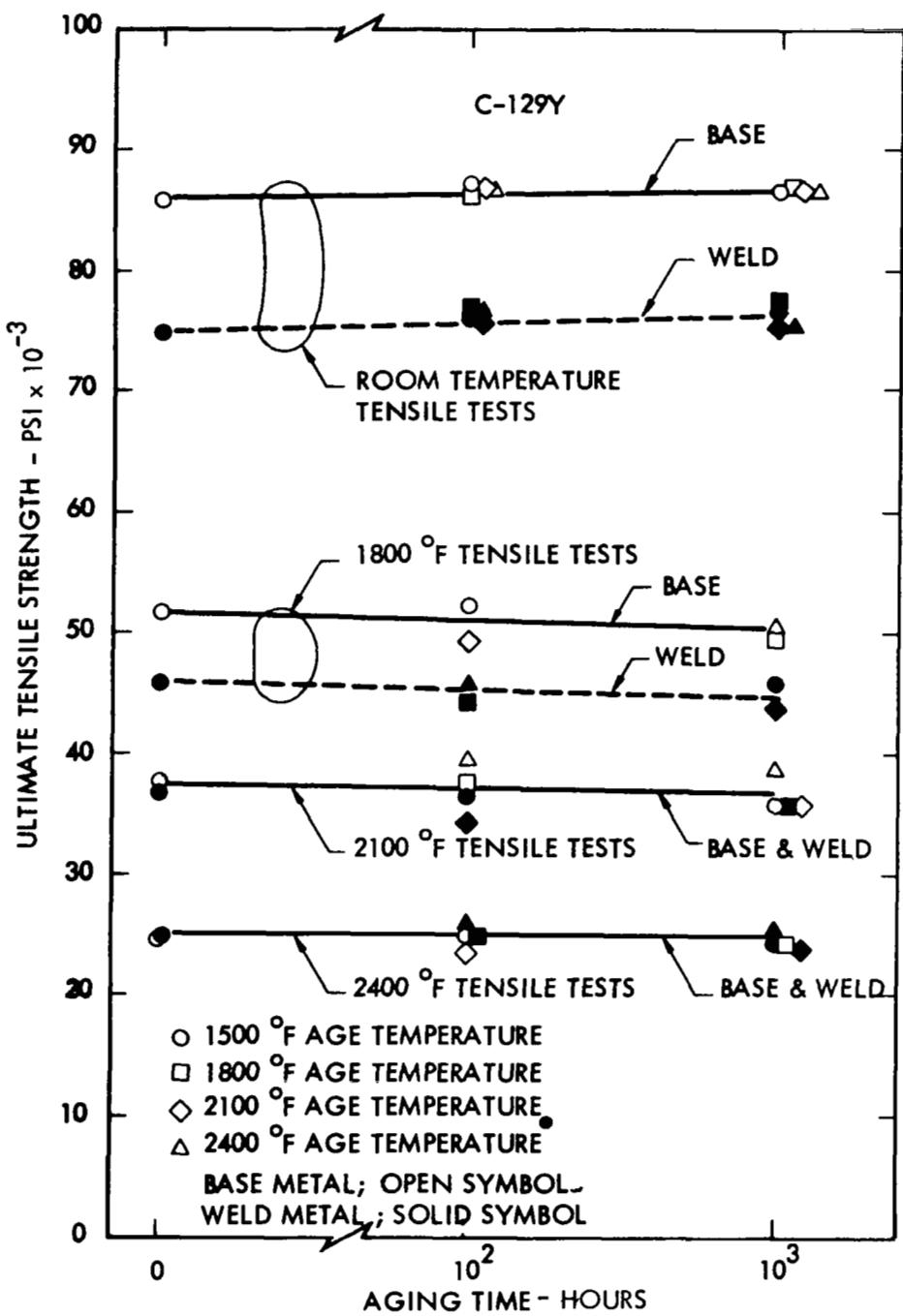


13,852 Base Metal of GTA Weld Specimen After 400X
1 Hr.-2200°F PWA + 1000 Hrs.-1500°F Age



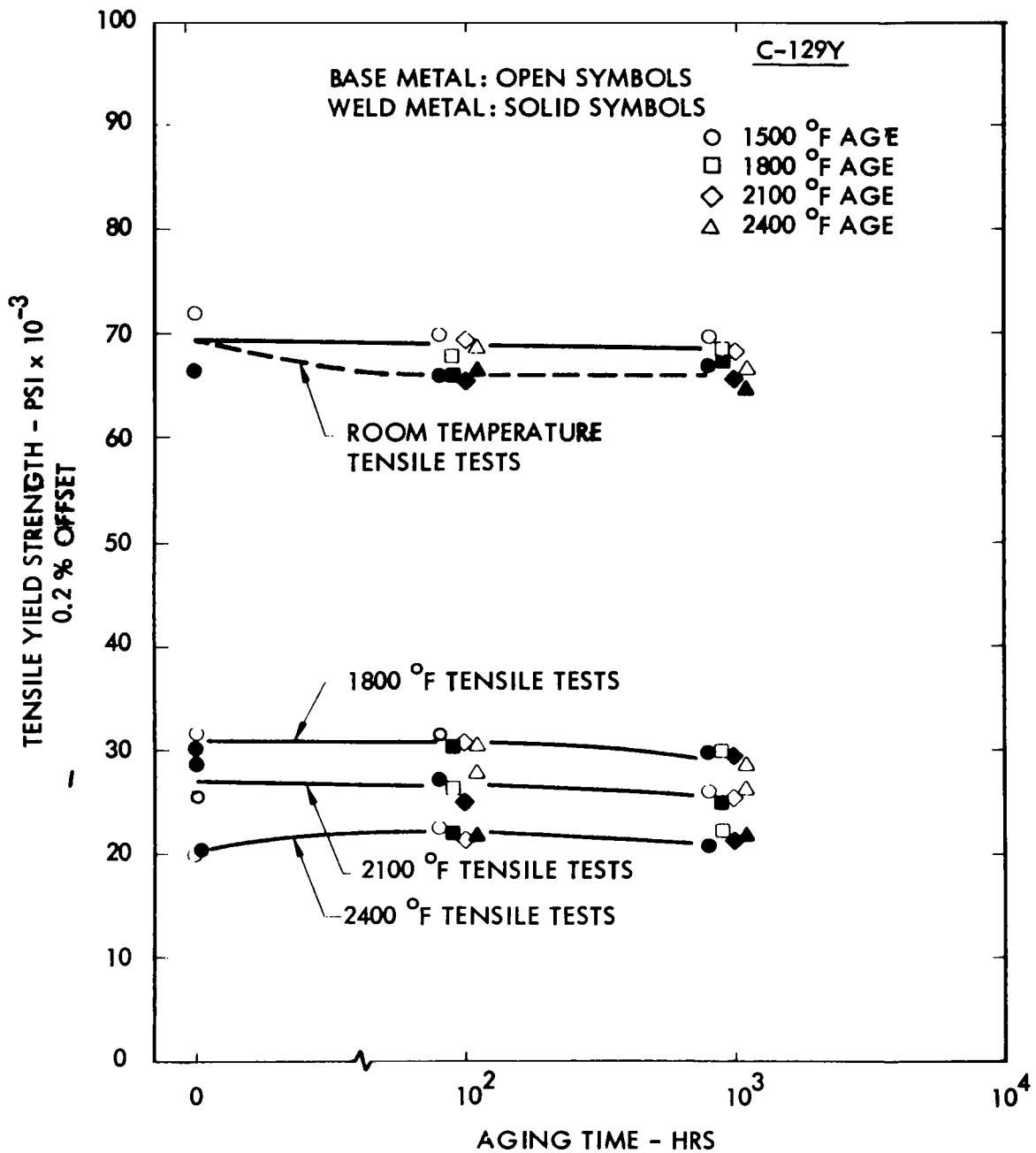
13,856 Base Metal of GTA Weld Specimen After 400X
1 Hr.-2200°F PWA + 1000 Hrs.-2400°F Age

FIGURE A68 - Microstructures of Cb-752 GTA Weld Specimens.
Thermal History as Indicated.



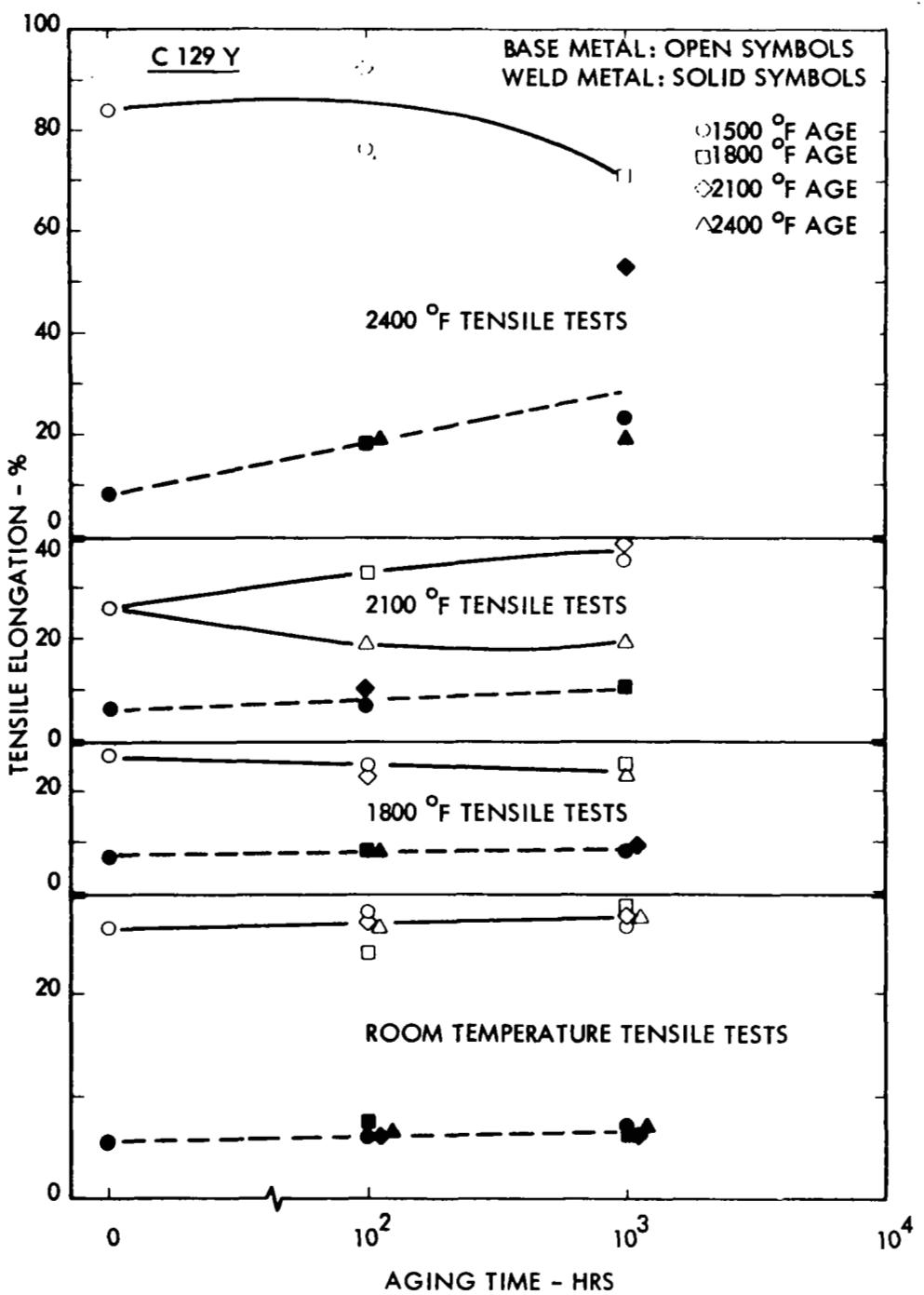
NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hour at 2400°F Prior to Aging and Testing.

FIGURE A69 - Ultimate Tensile Strength of C-129Y as a Function of Aging Parameters.



NOTE: Optimum Weld Parameters, All Samples Annealed
1 Hour at 2400°F Prior to Aging and Testing.

FIGURE A70 – Tensile Yield Strength of C-129Y as a Function of Aging Parameters.



NOTE: Optimum Weld Parameters, All Samples Annealed
1 Hour at 2400°F Prior to Aging and Testing.

FIGURE A71 - Tensile Elongation of C-129Y as a Function of Aging Parameters.

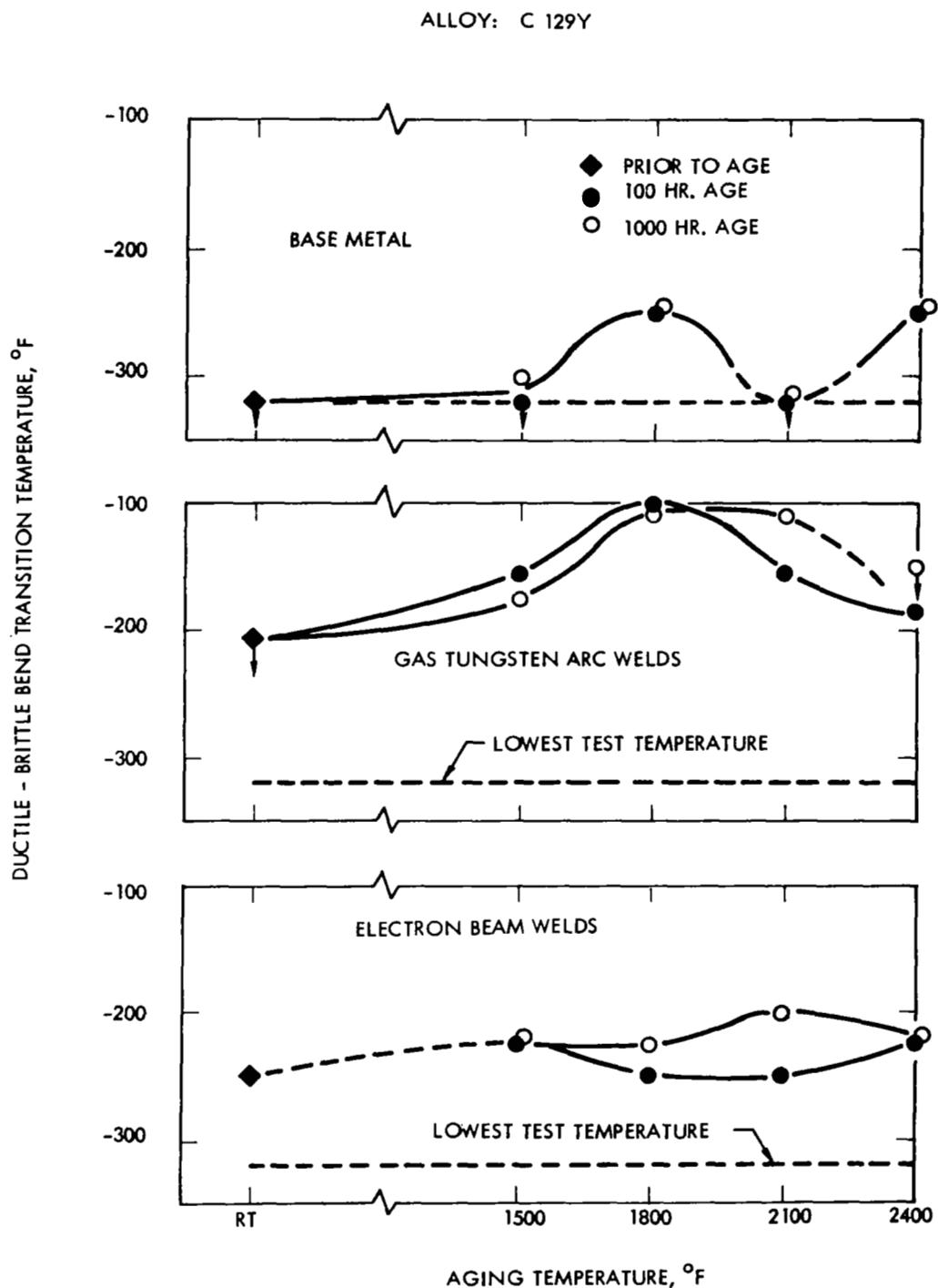
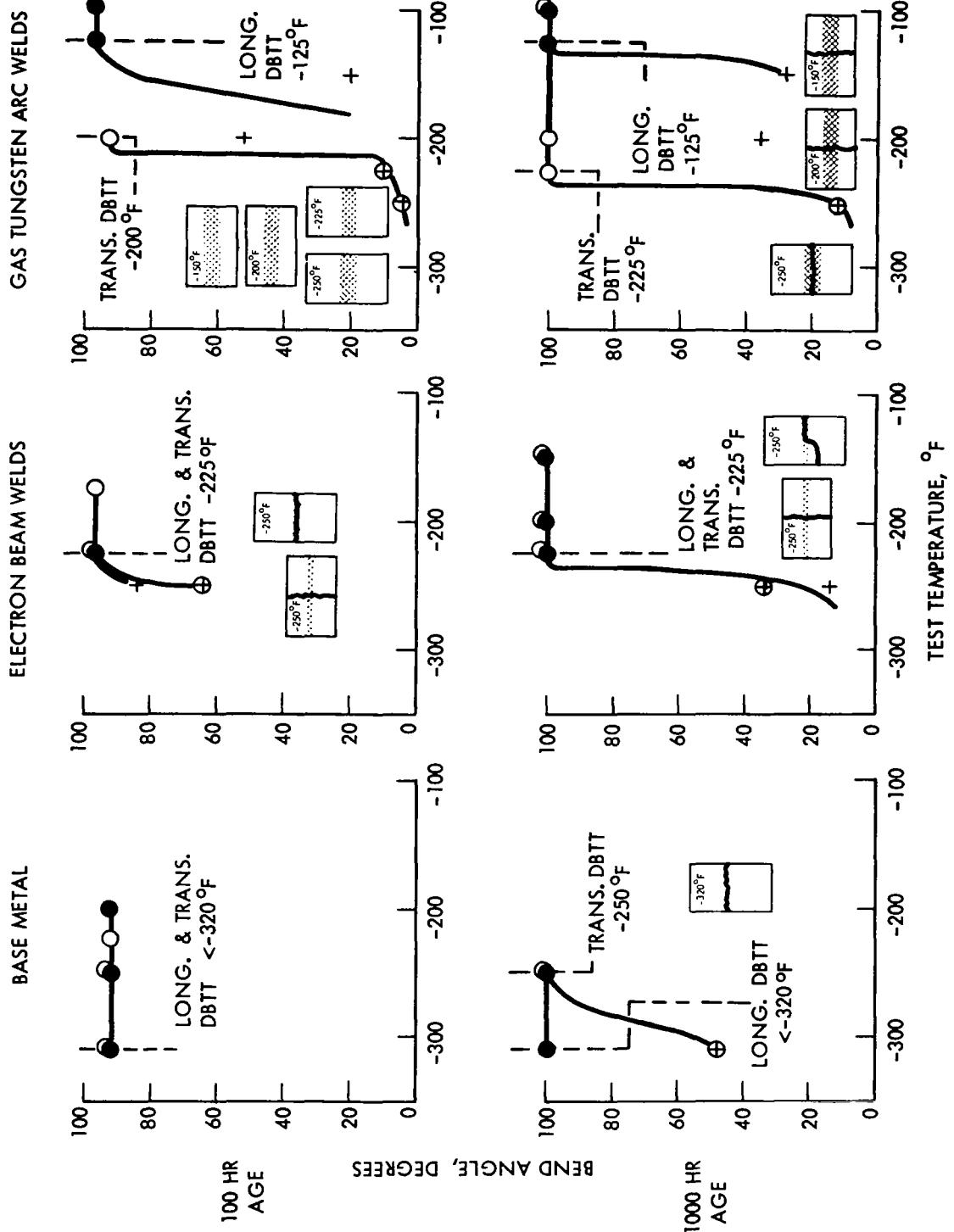


FIGURE A72 - Bend Ductile-Brittle Transition Temperature of C-129Y As A Function of Aging Parameters (1t Bend Radius).



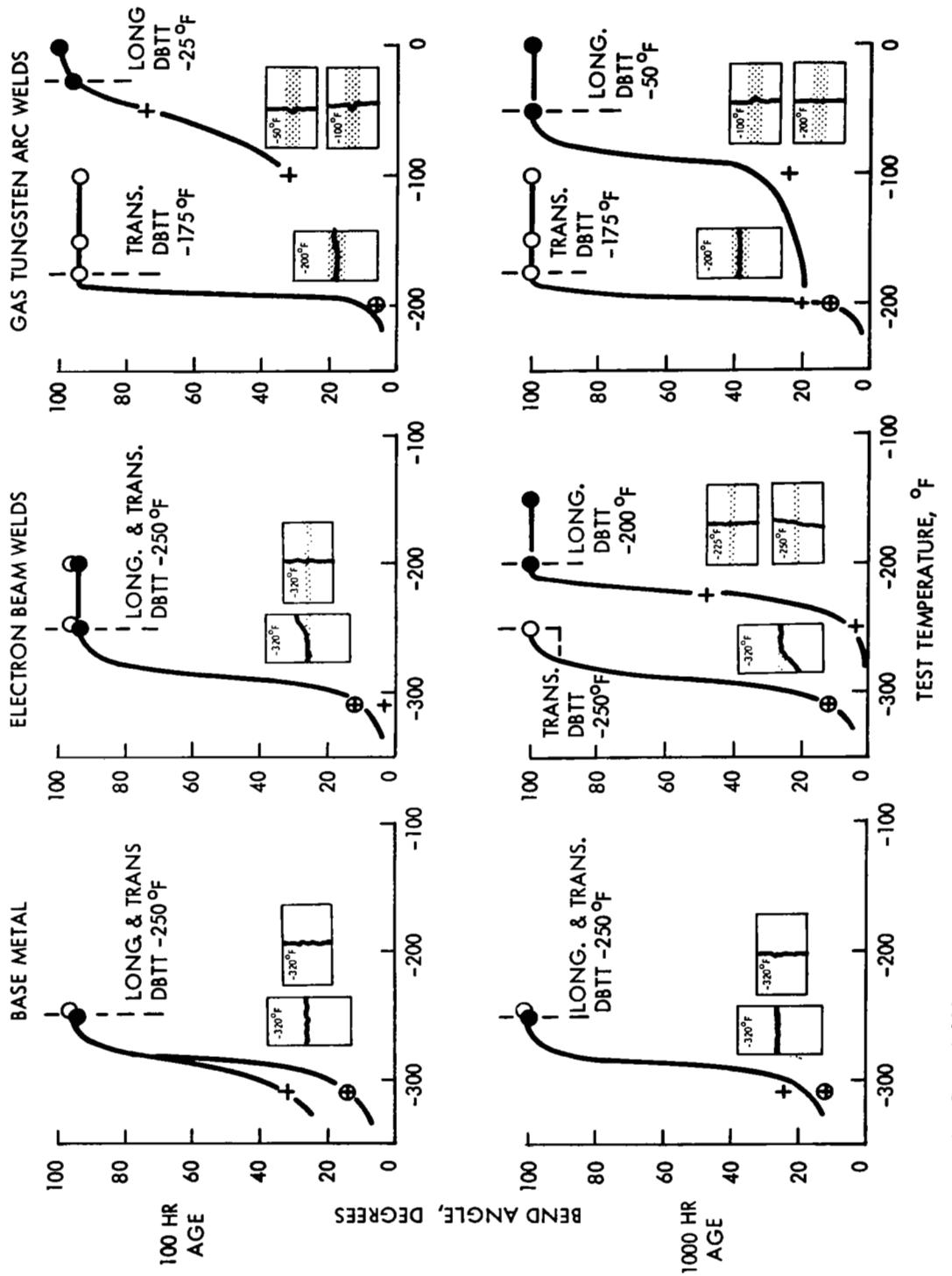


FIGURE A74 - Bend Test Results for C-129Y Aged 100 and 1000 Hours at 1800°F
(1t Bend Radius)

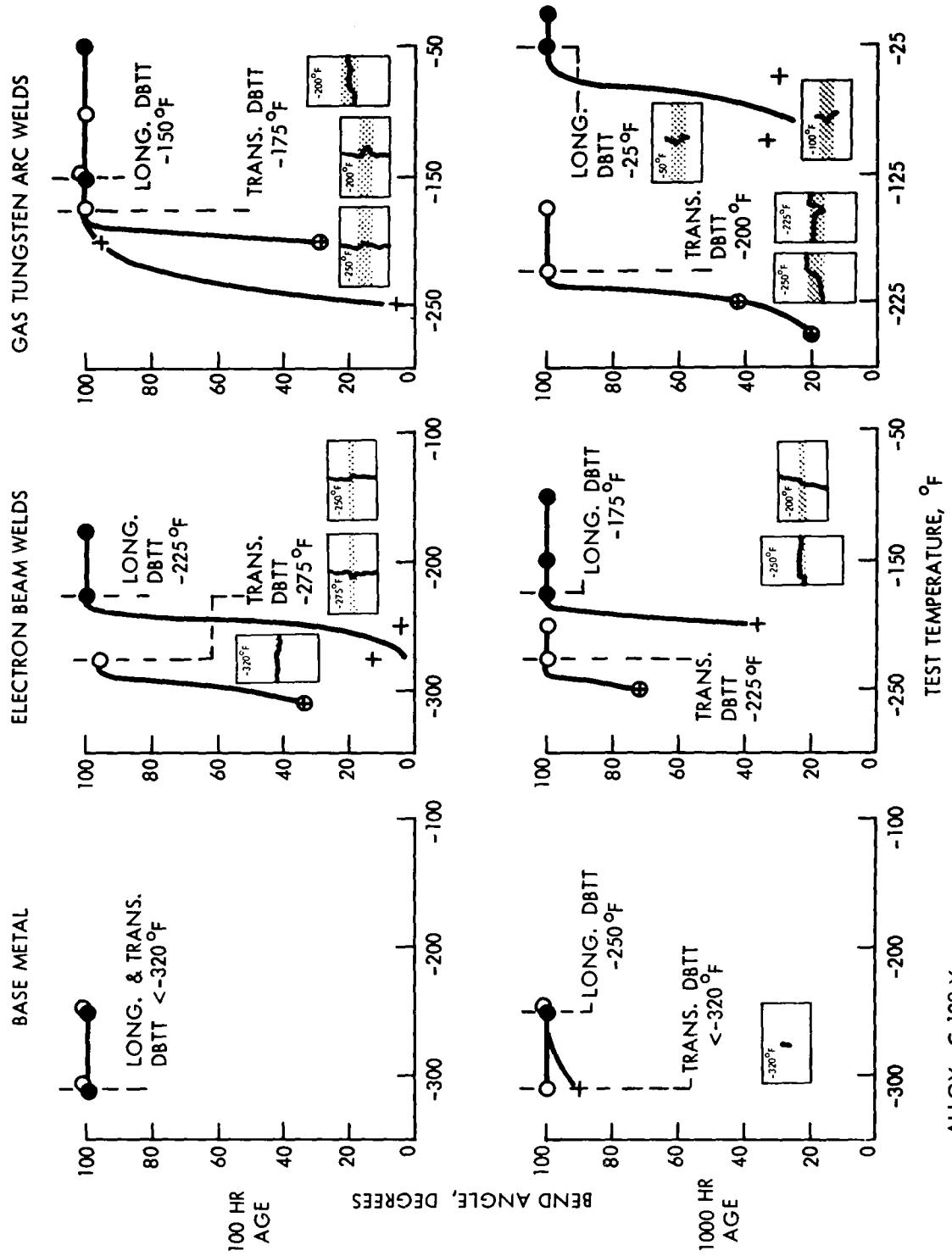
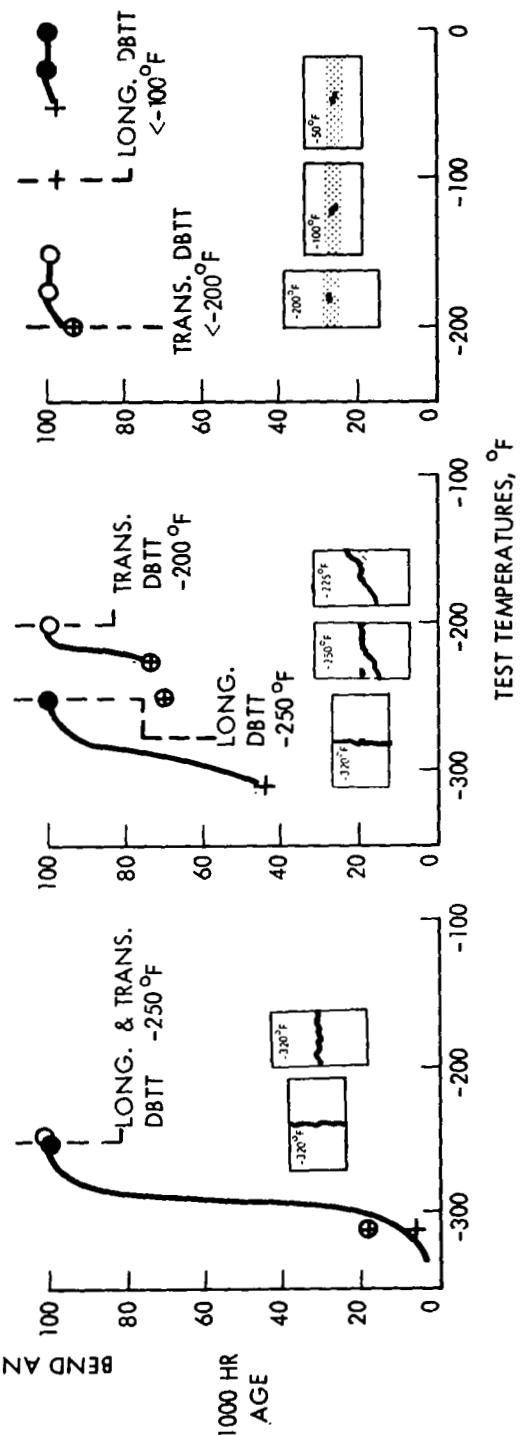
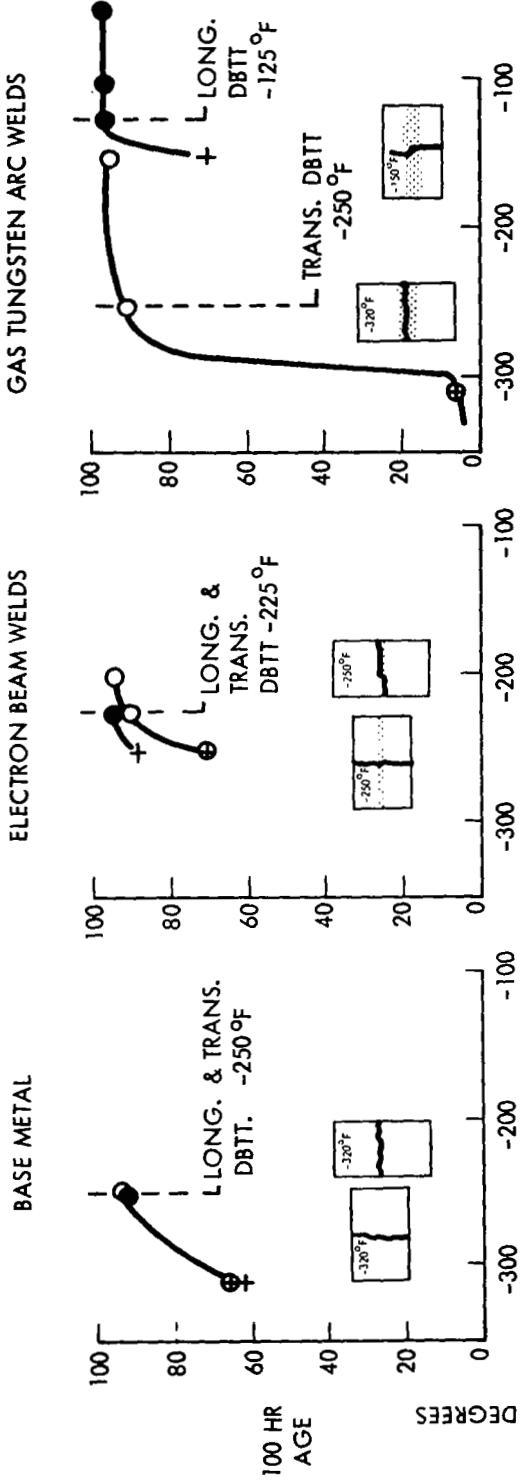


FIGURE A75 - Bend Test Results for C-129Y Aged 100 and 1000 Hours at 2100°F (1t Bend Radius)

BASE METAL

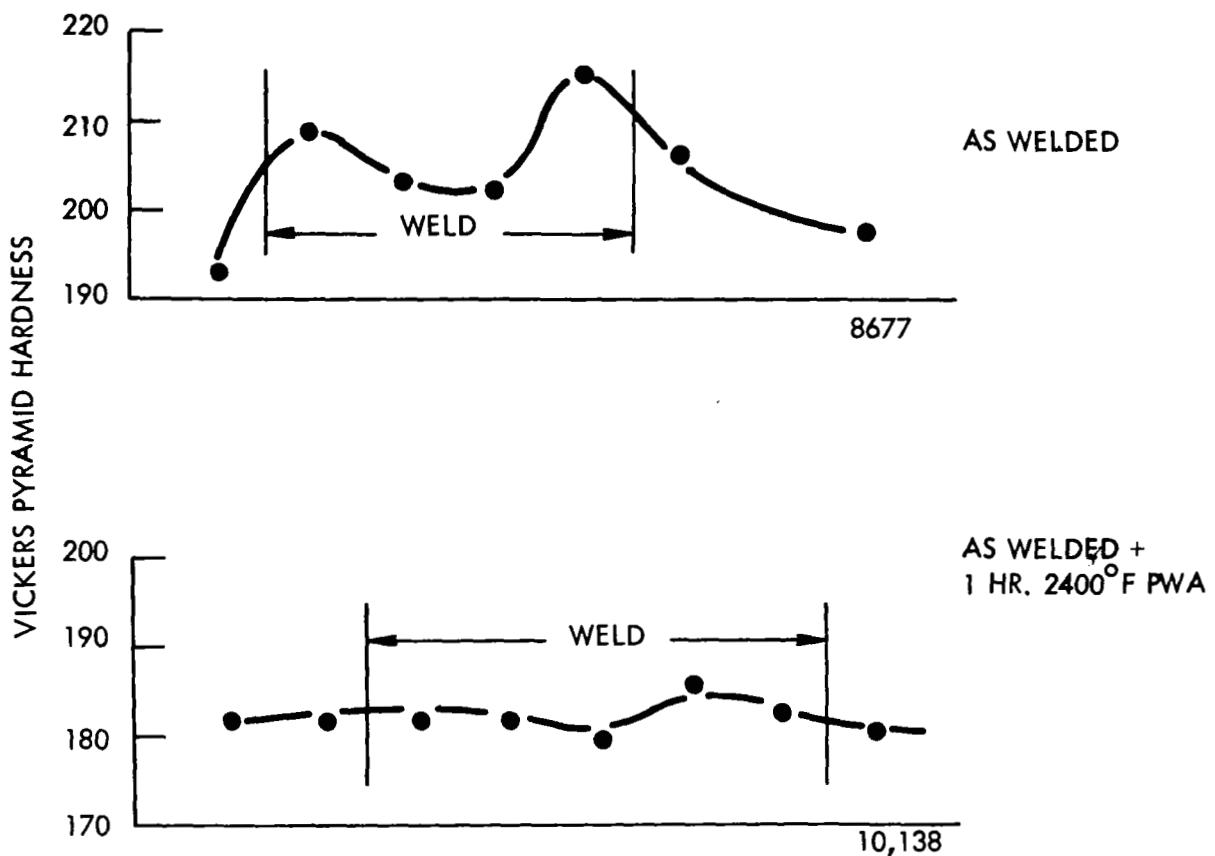
ELECTRON BEAM WELDS

100 HR AGE



ALLOY: C129Y
AGING TEMP: 2400 °F

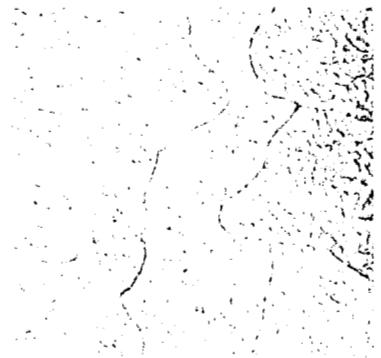
FIGURE A76 - Bend Test Results for C-129Y Aged 100 and 1000 Hours at 2400 °F.
(1t Bend Radius)



**FIGURE A77 - Hardness Traverses for C-129Y GTA Sheet Welds.
Thermal History as Indicated. (10 Kg. Load on
Vickers Hardness Tester.)**

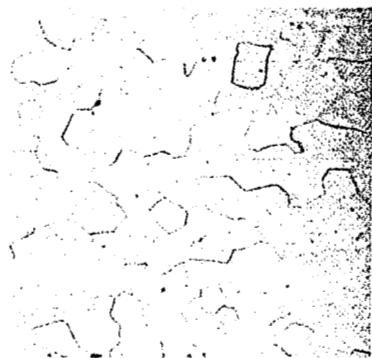


10,138 Base Metal 400X

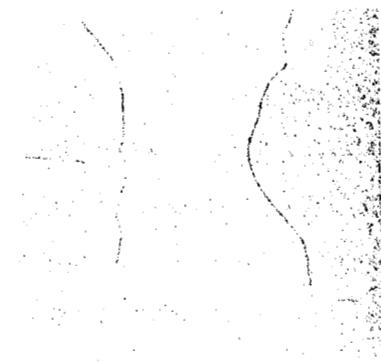


10,138 Weld Zone 400X

a) GTA Weld Specimen Following 1Hr-2400°F PWA



13,866 Base Metal 400X



13,866 Weld Zone 400X

b) GTA Weld Specimen Following 1 Hr.-2400°F PWA +
1000 Hours - 2100°F Age

Note the yttria appears to have been more effective in controlling
the grain size of the base metal than that of the weld fusion zone.

FIGURE A78 - Microstructures of C-129Y GTA Weld Specimens. Thermal History As Indicated.

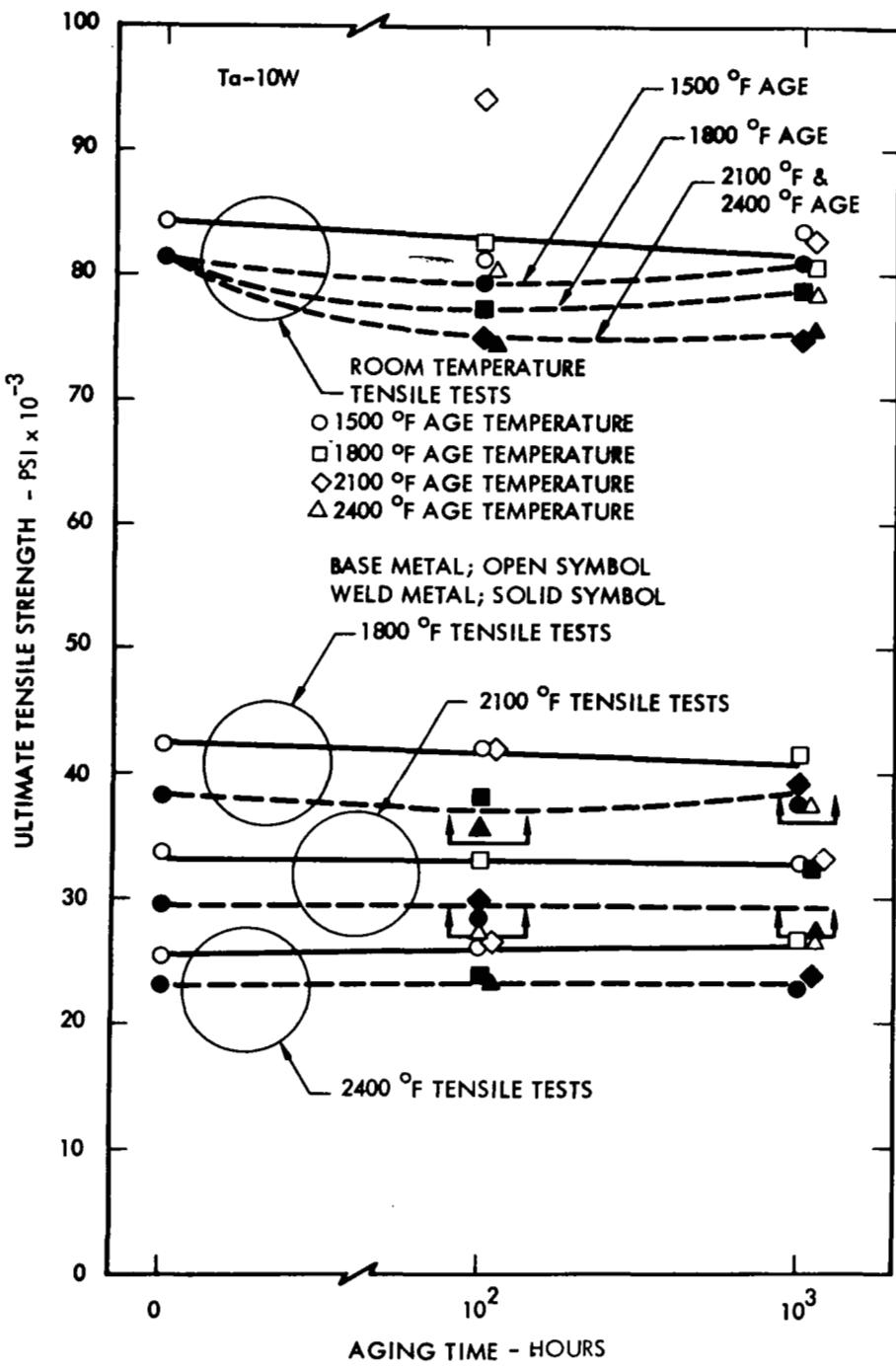


FIGURE A79 - Ultimate Tensile Strength of Ta-10W as a Function of Aging Parameters.

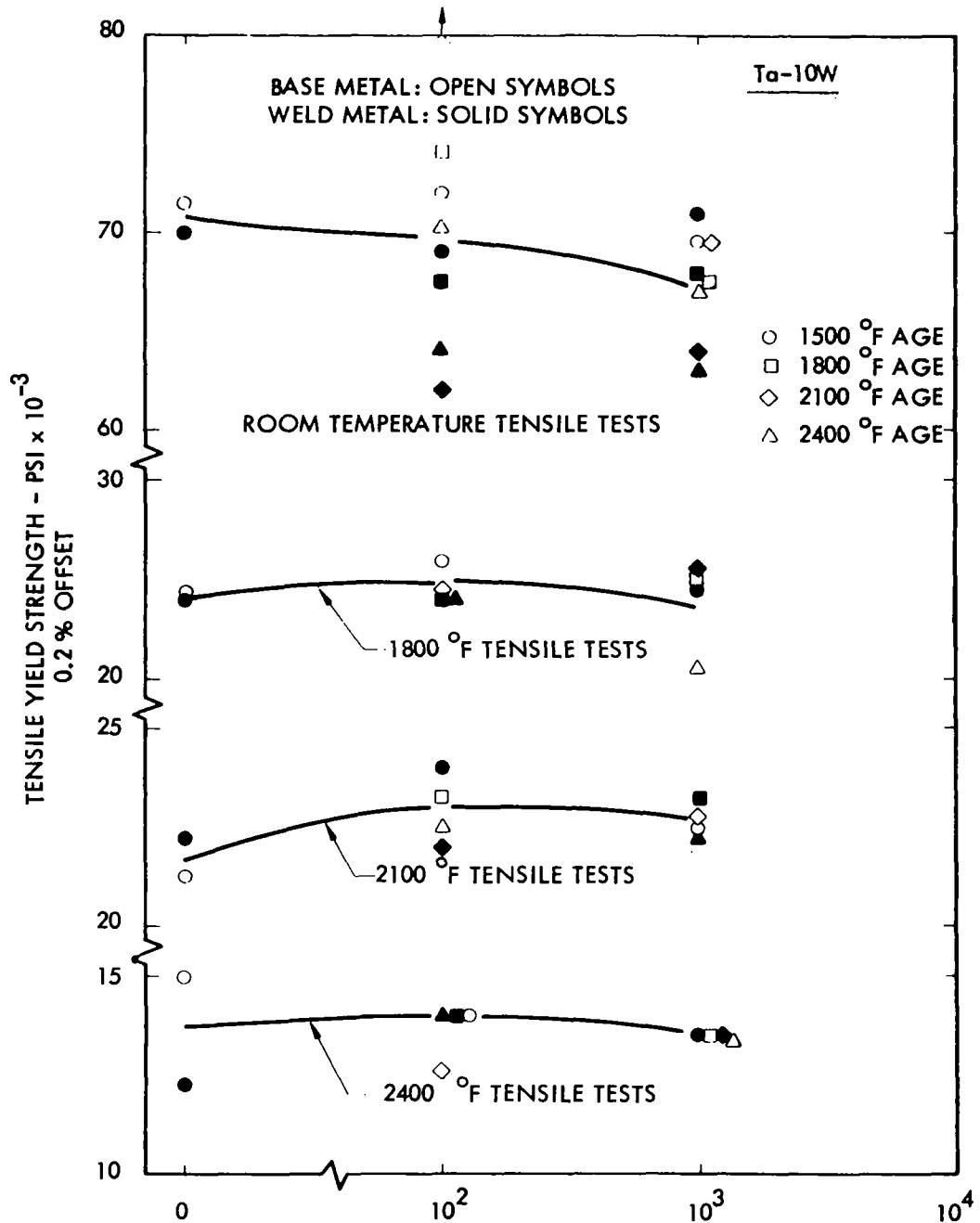
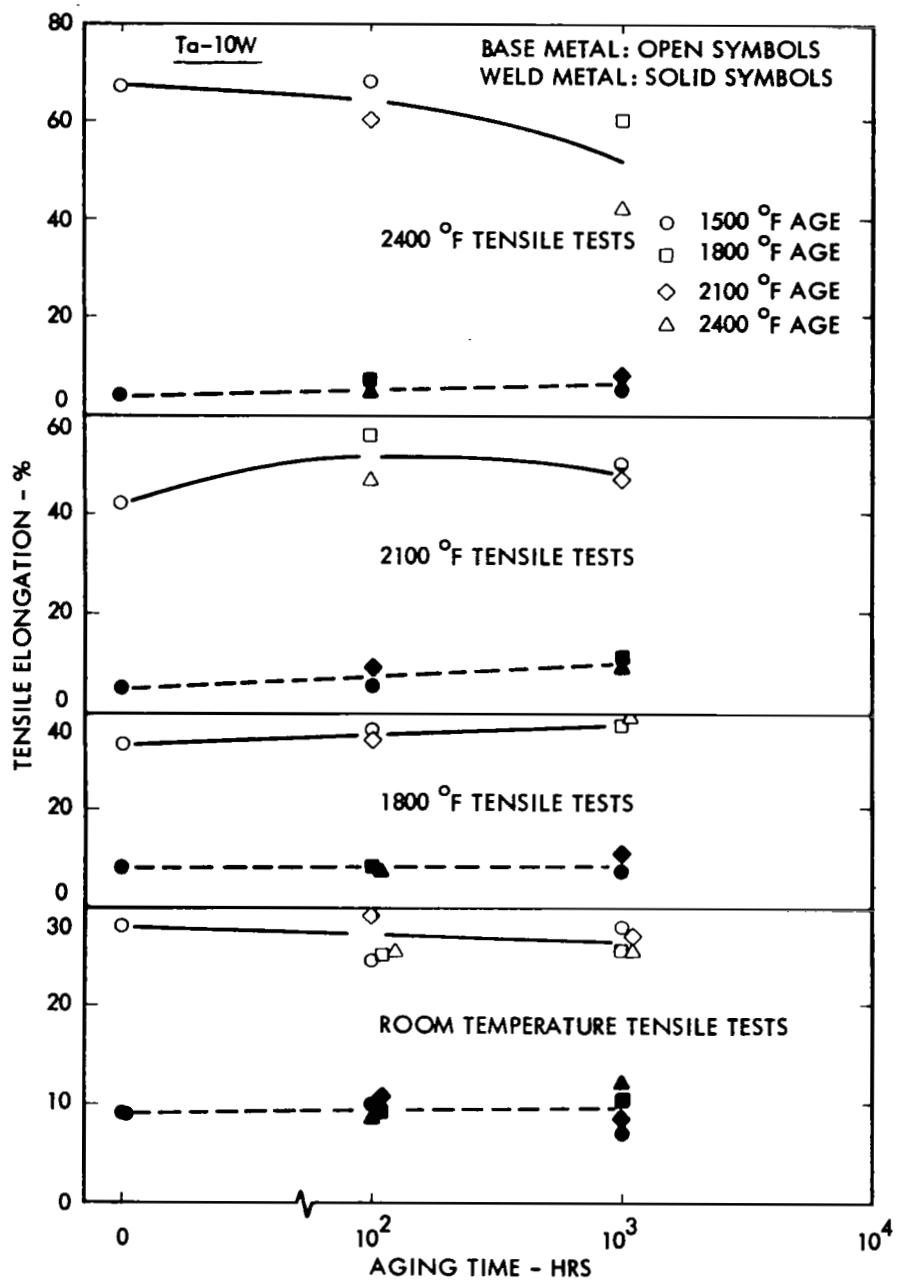


FIGURE A80 - Tensile Yield Strength of Ta-10W as a Function of Aging Parameters.



NOTE: Optimum Weld Parameters, Samples Not Post Weld Annealed Prior to Aging and Testing.

FIGURE A81 – Tensile Elongation of Ta-10W as a Function of Aging Parameters.

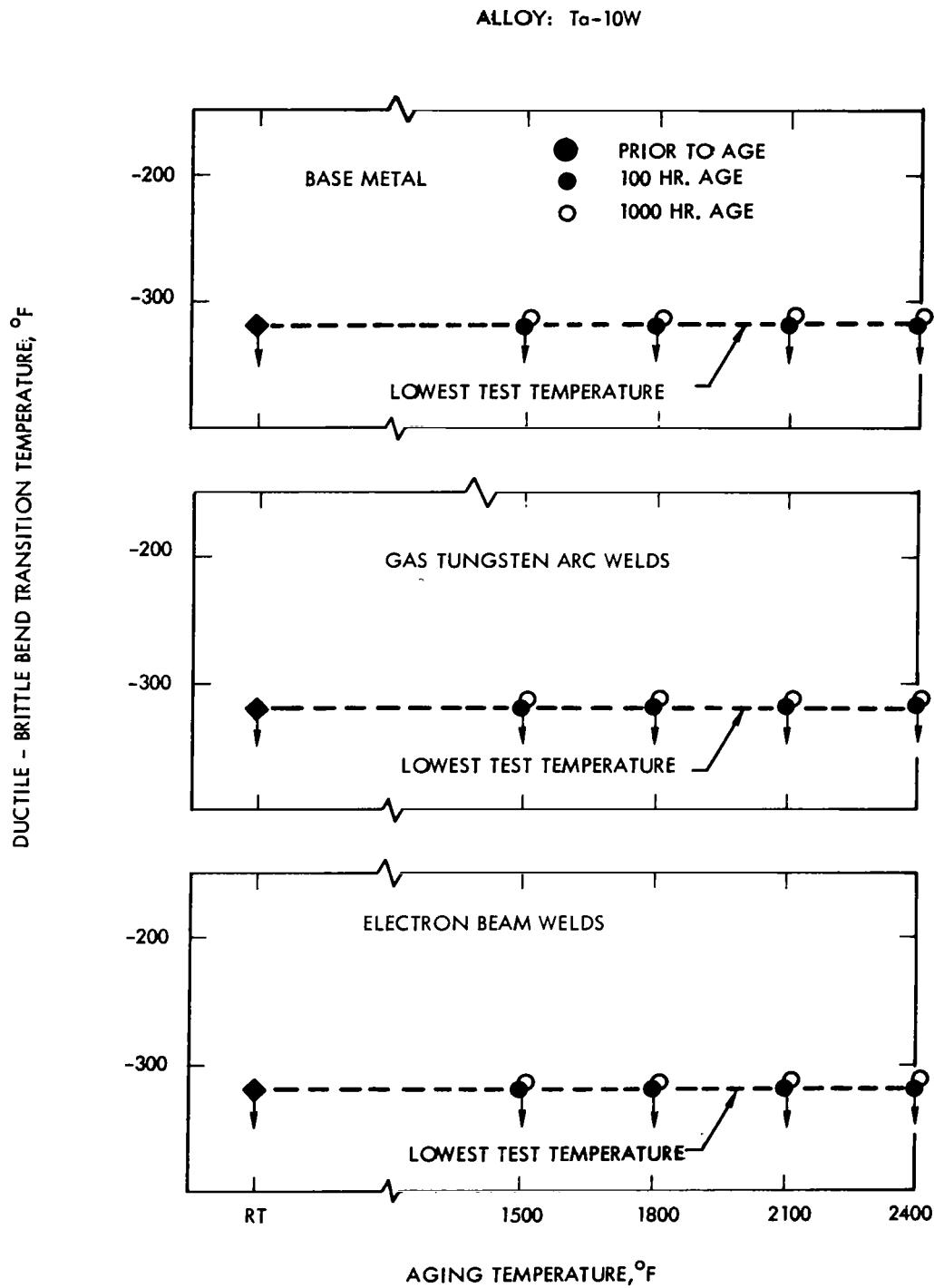
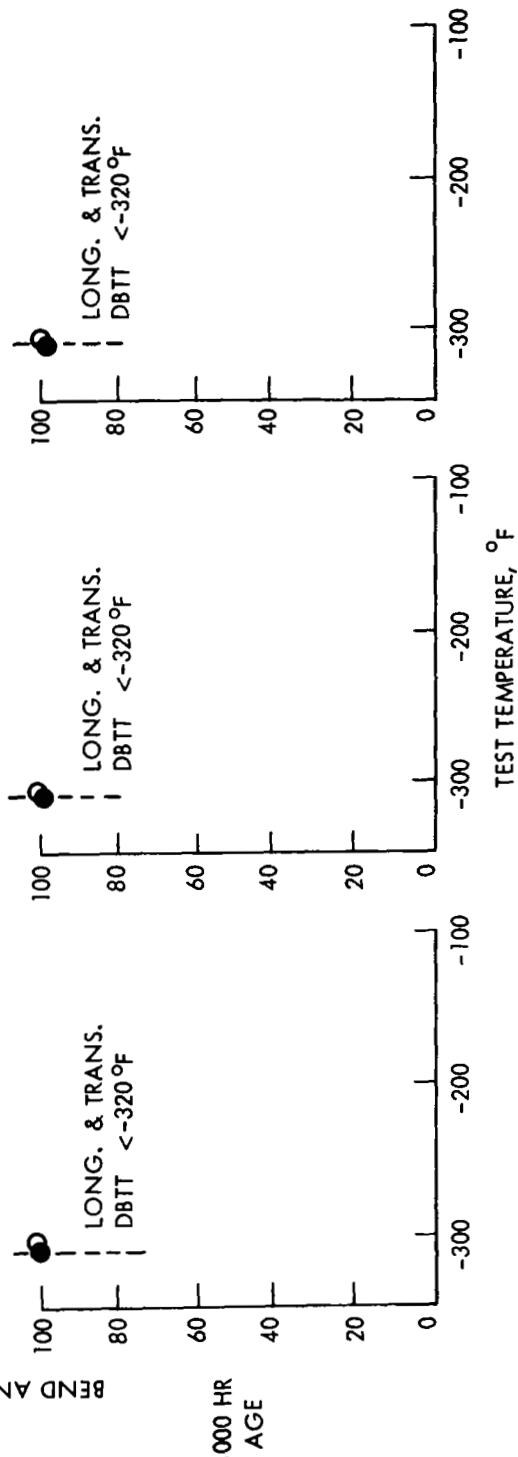
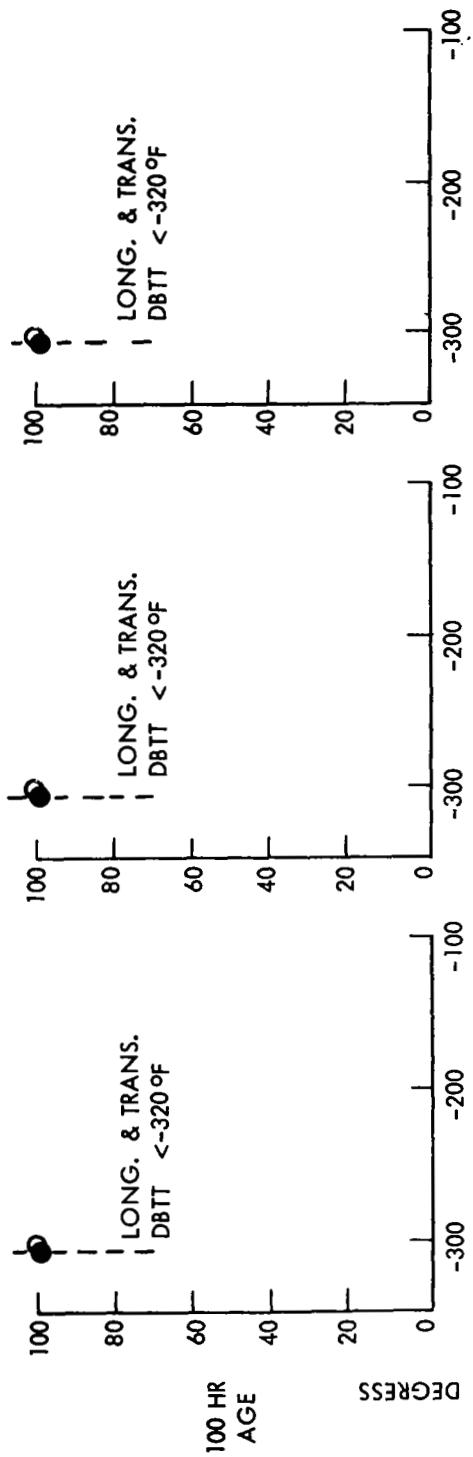


FIGURE A82 - Bend Ductile-Brittle Transition Temperature of Ta-10W As A Function of Aging Parameters (1t Bend Radius).

GAS TUNGSTEN ARC WELDS

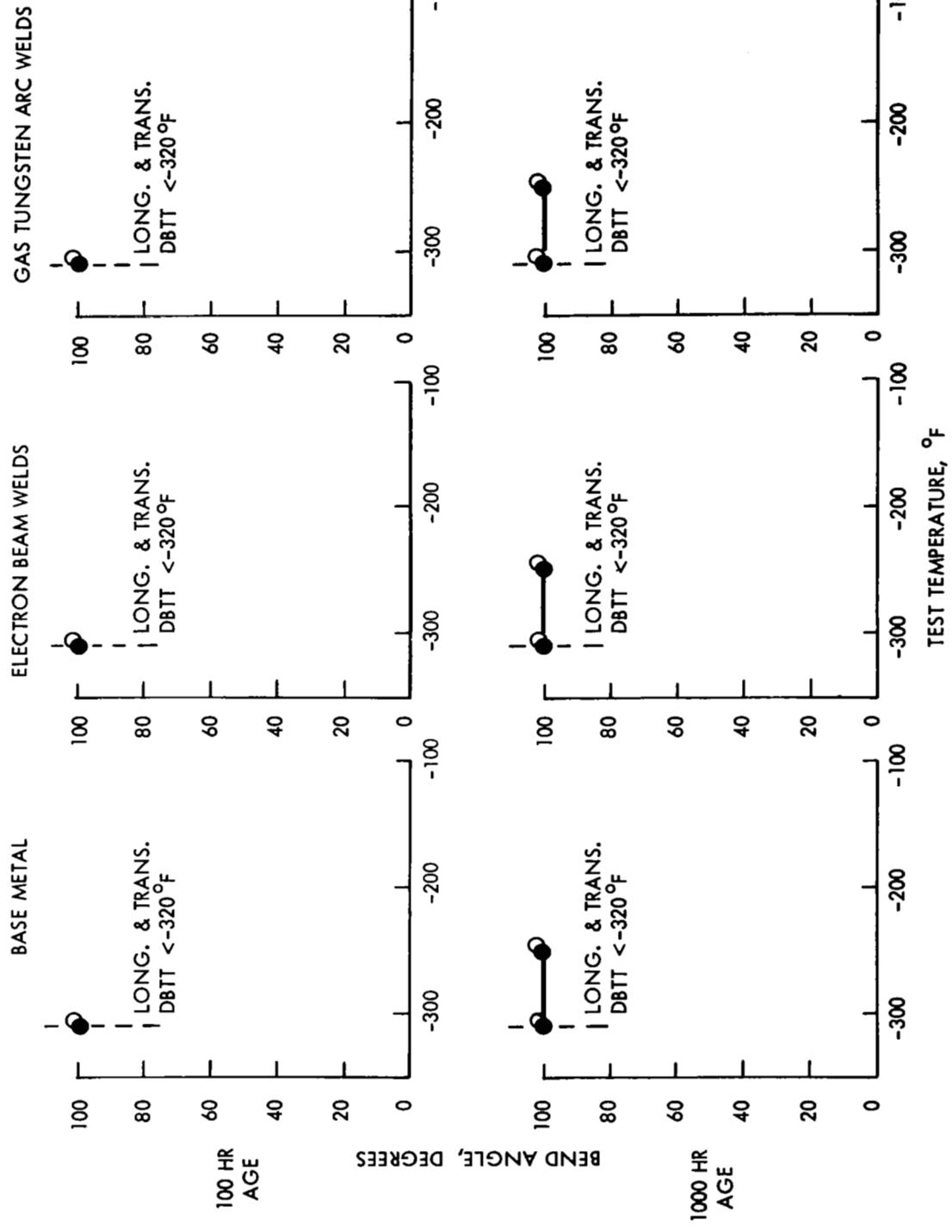
ELECTRON BEAM WELD

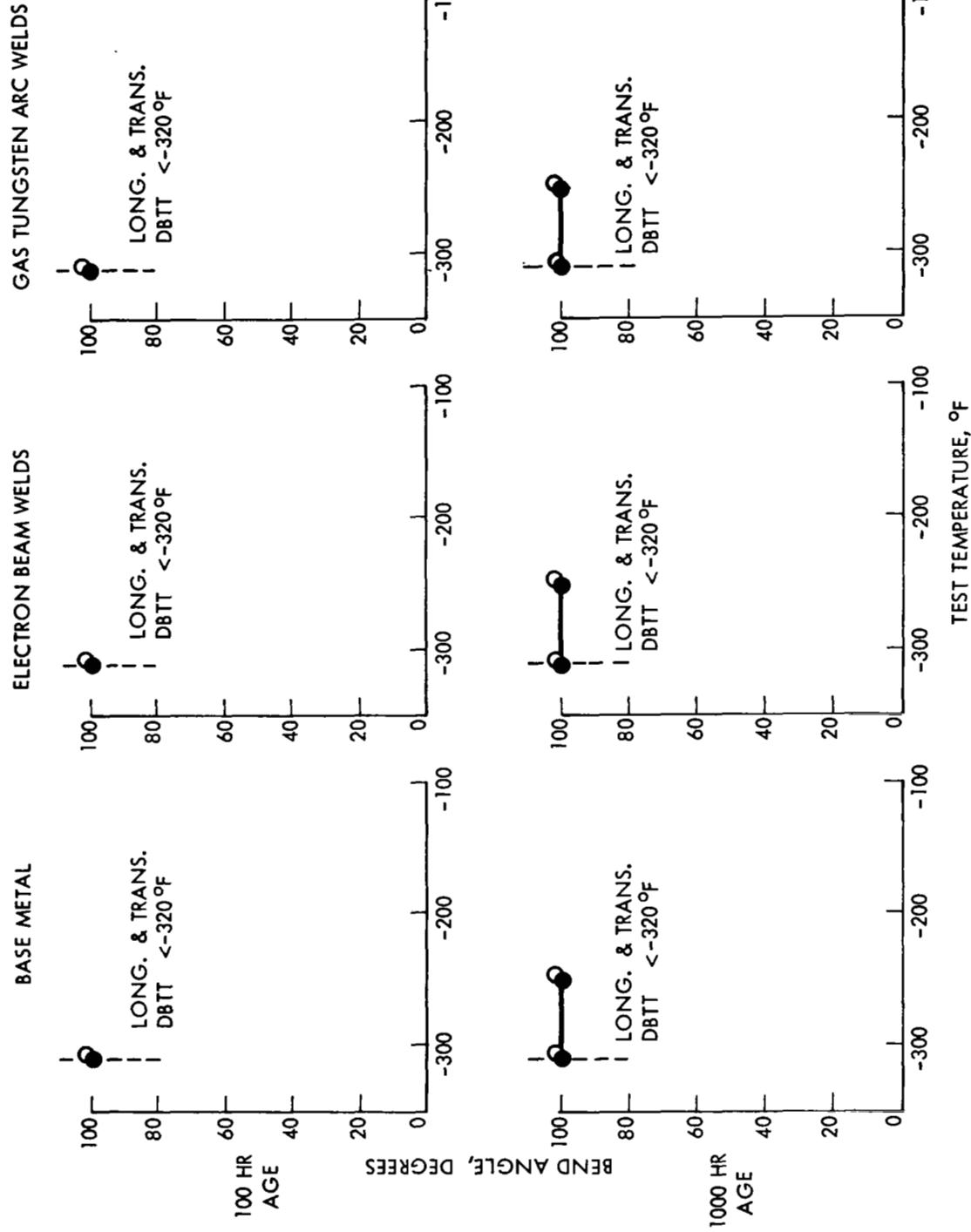
BASE METAL



ALLOY: Ta-10W
AGING TEMP: 1500 °F

FIGURE A83 – Bend Test Results for Ta-10W Aged 100 and 1000 Hours at 1500°F (1t Bend Radius)



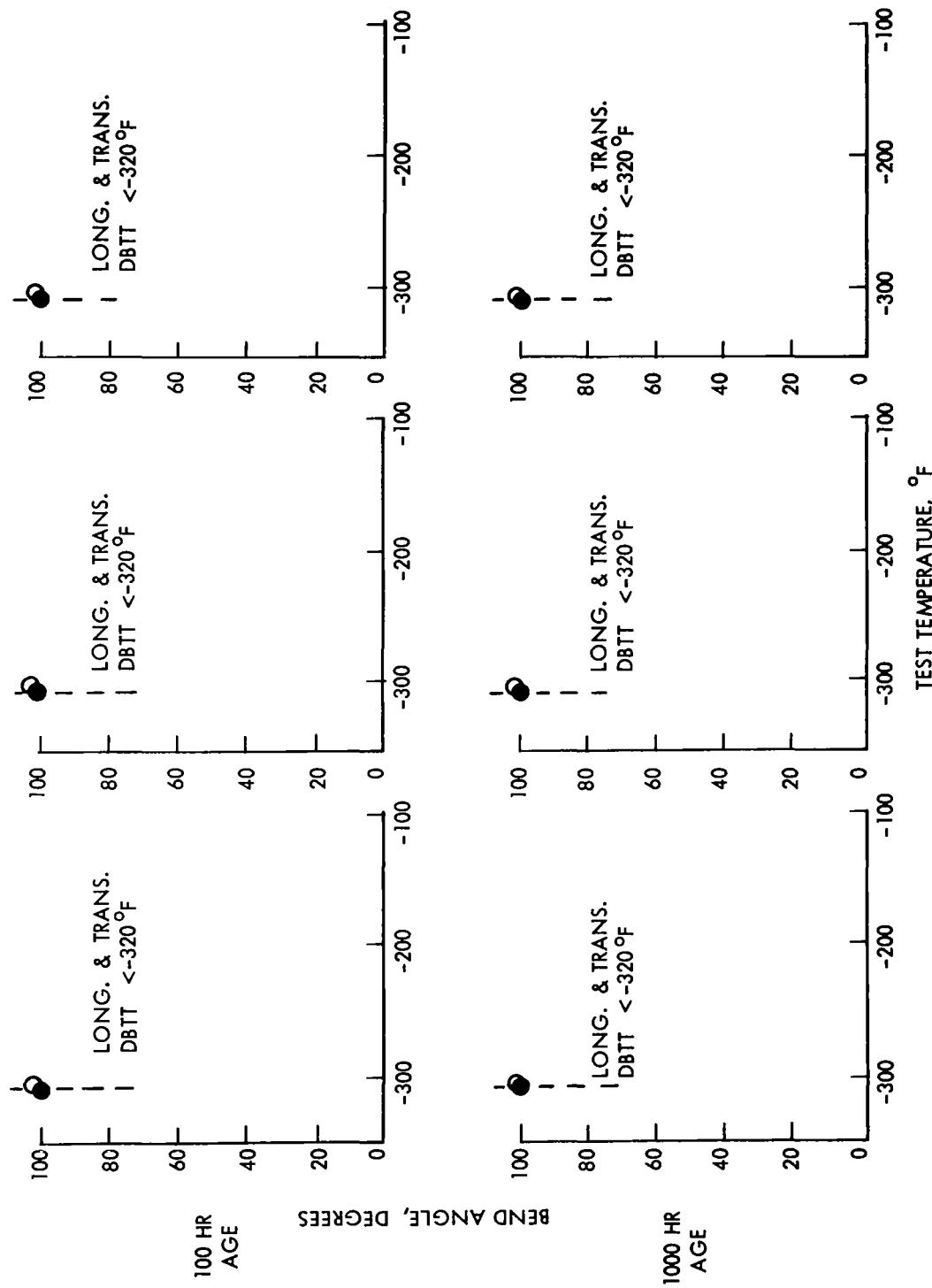


ALLOY: Ta - 10W
AGING TEMP: 2100 °F

FIGURE A85 - Bend Test Results for Ta-10W Aged 100 and 1000 Hours at 2100°F (1 ft Bend Radius).

GAS TUNGSTEN ARC WELDS

ELECTRON BEAM WELDS



ALLOY: Ta-10W
AGING TEMP: 2400 °F

FIGURE A86 - Bend Test Results for Ta-10W Aged 100 and 1000 Hours at 2400°F
(1f Bend Radius)

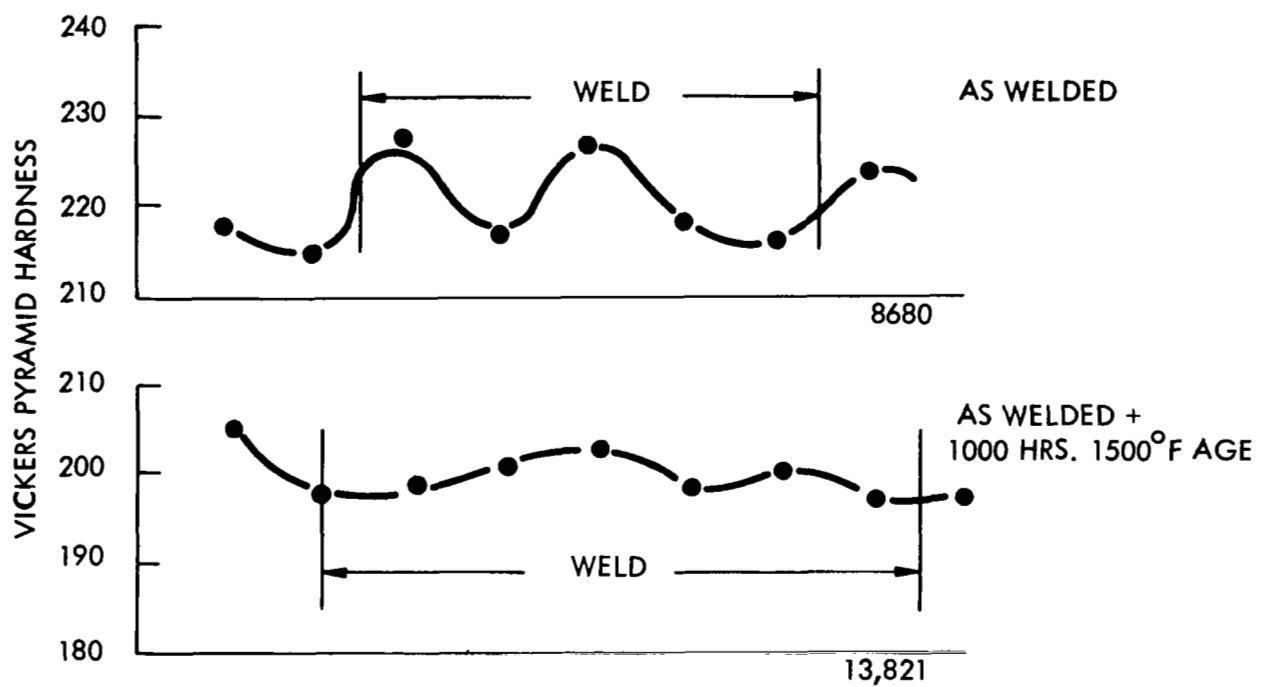
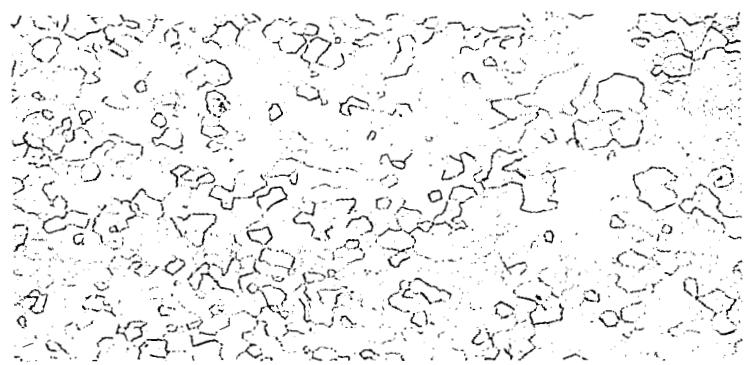


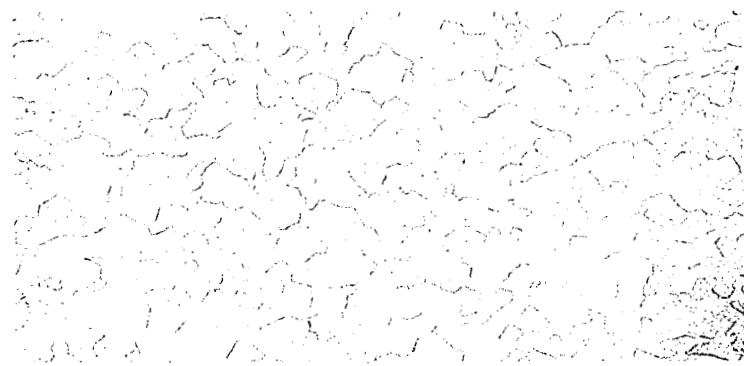
FIGURE A87 - Hardness Traverses for Ta-10W GTA Sheet Welds. Thermal History as Indicated. (10 Kg. Load on Vickers Hardness Tester.)



8680 Base Metal of GTA Weld - As Welded 100X



13,822 Base Metal of GTA Weld Specimen After 80X
1000 Hrs.-1800°F Age



13,824 Base Metal of GTA Weld Specimen After 80X
1000 Hrs.-2400°F Age

FIGURE A88 - Microstructures of Ta-10W GTA Weld Specimens. Thermal History As Indicated.

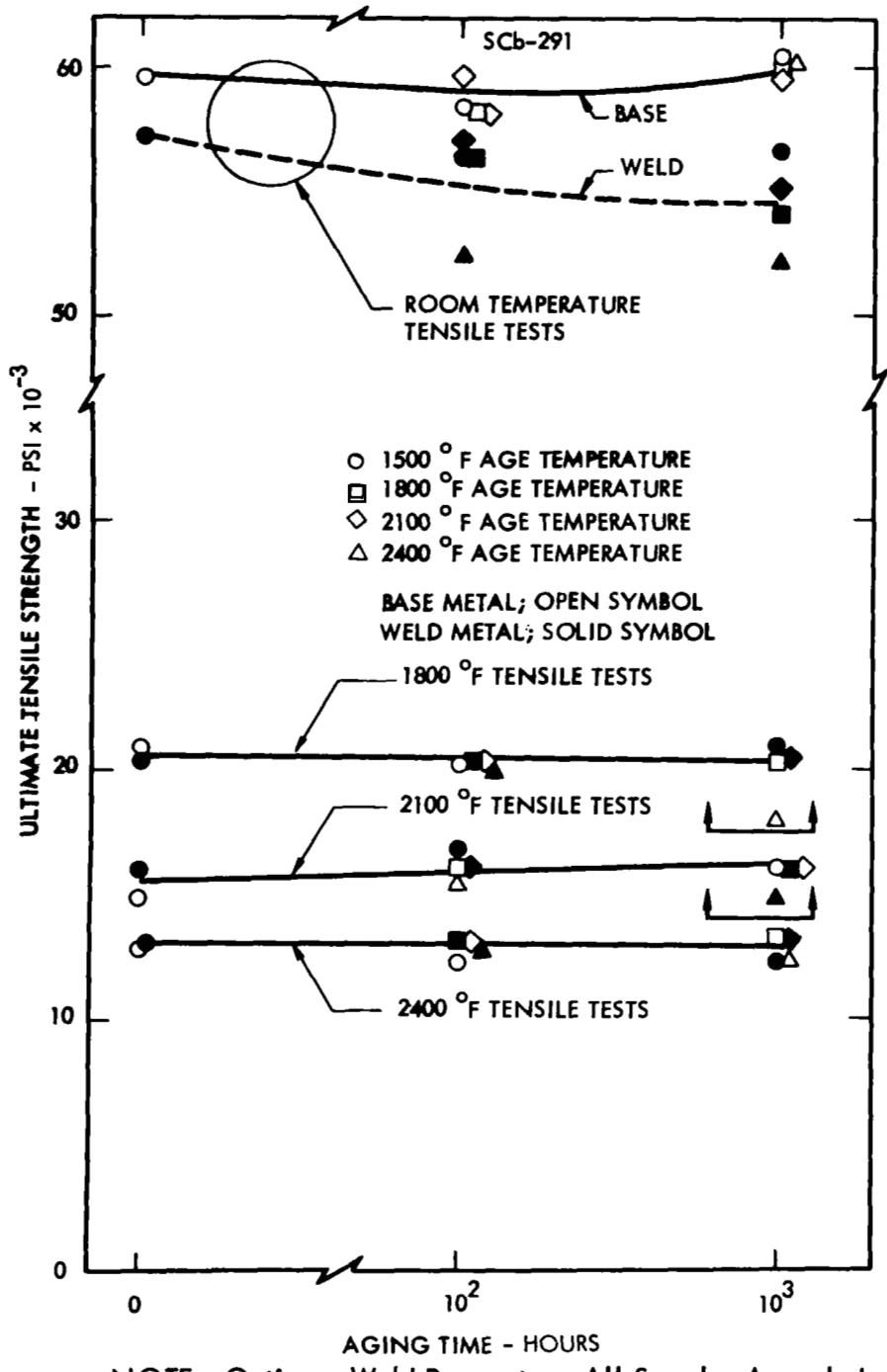
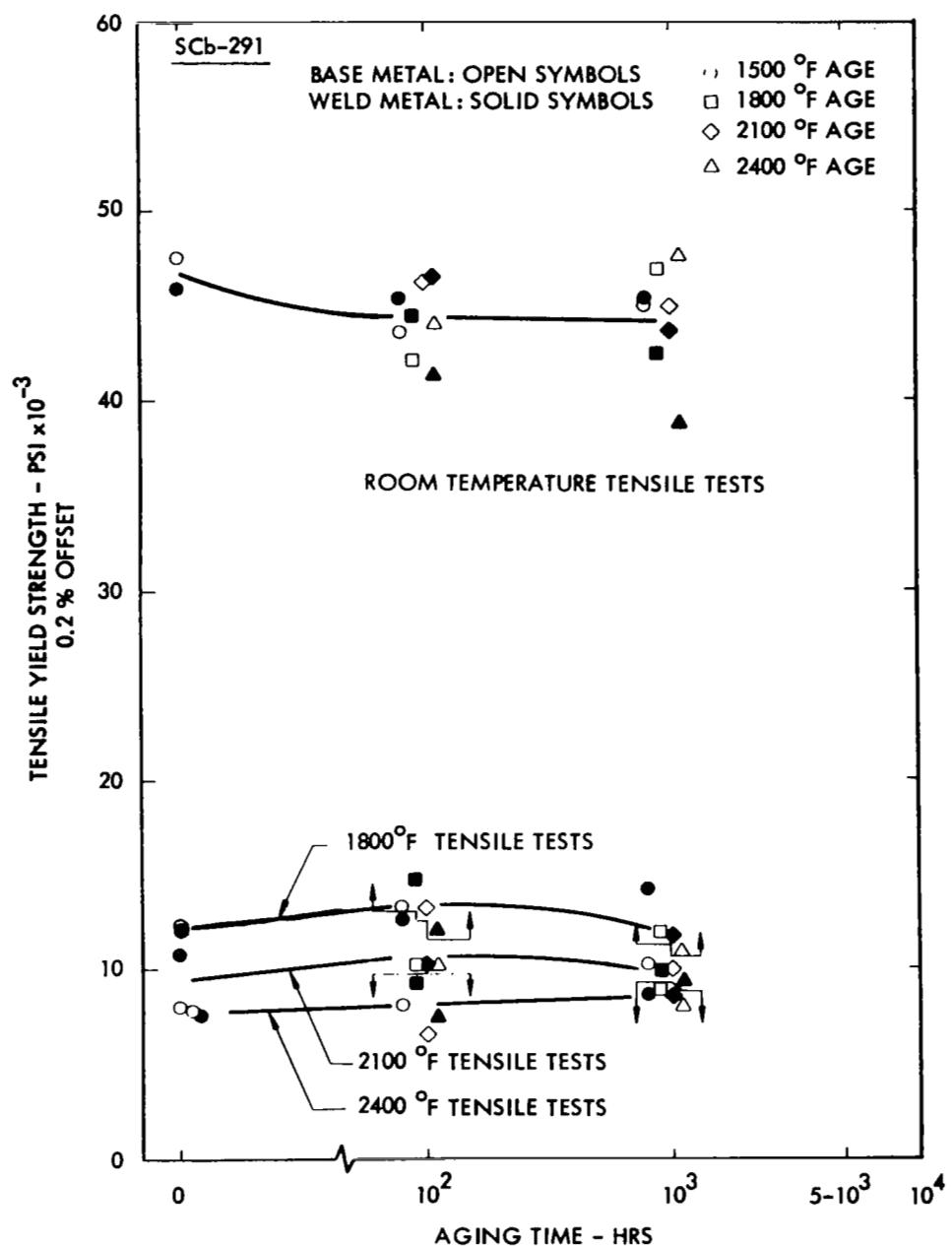


FIGURE A89 - Ultimate Tensile Strength of SCb-291 as a Function of Aging Parameters.



NOTE: Optimum Weld Parameters, All Samples Annealed 1 Hour at 2200°F Prior to Aging and Testing.

FIGURE A90 - Tensile Yield Strength of SCb-291 as a Function of Aging Parameters.

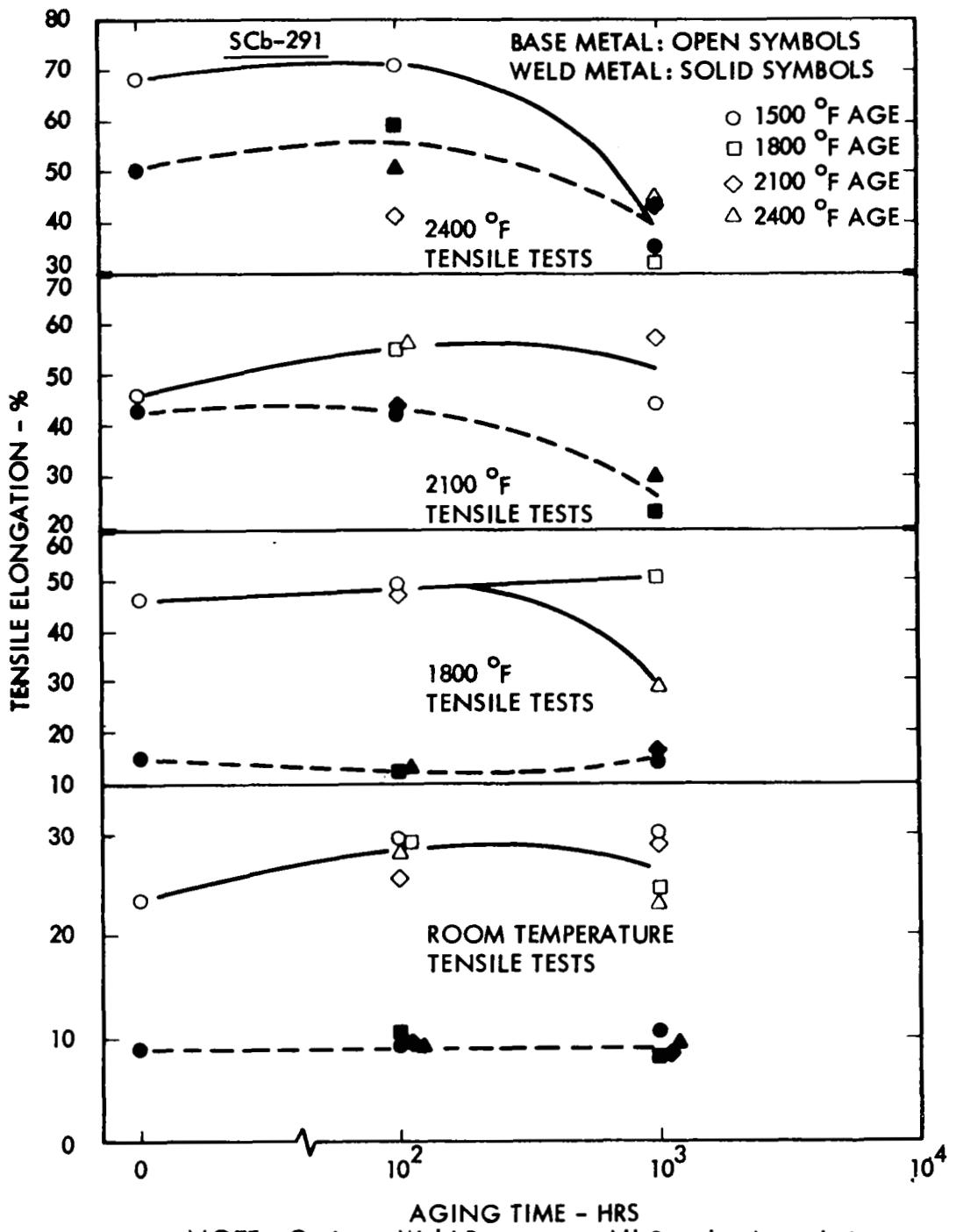


FIGURE A91 - Tensile Elongation of SCb-291 as a Function of Aging Parameters.

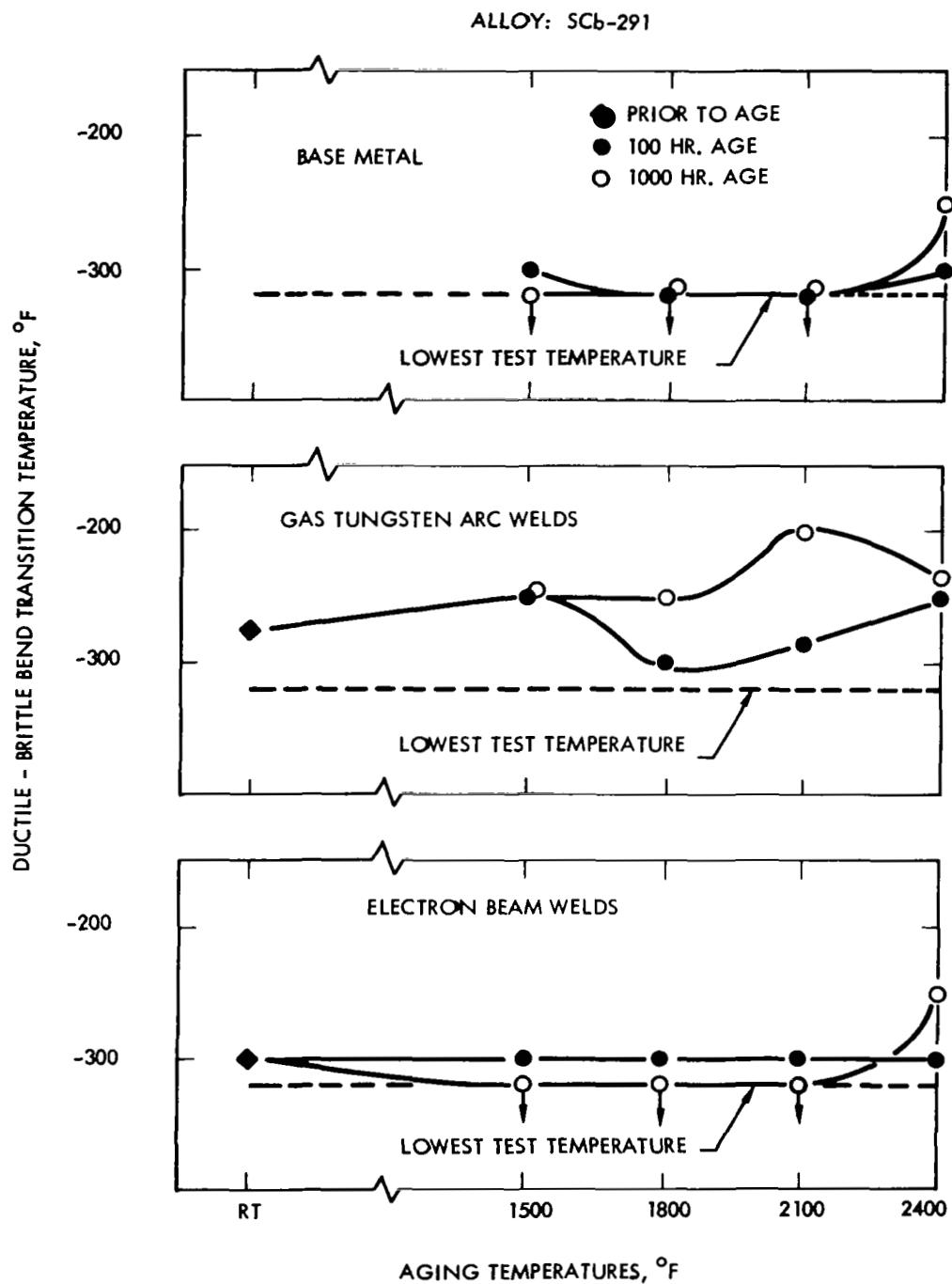
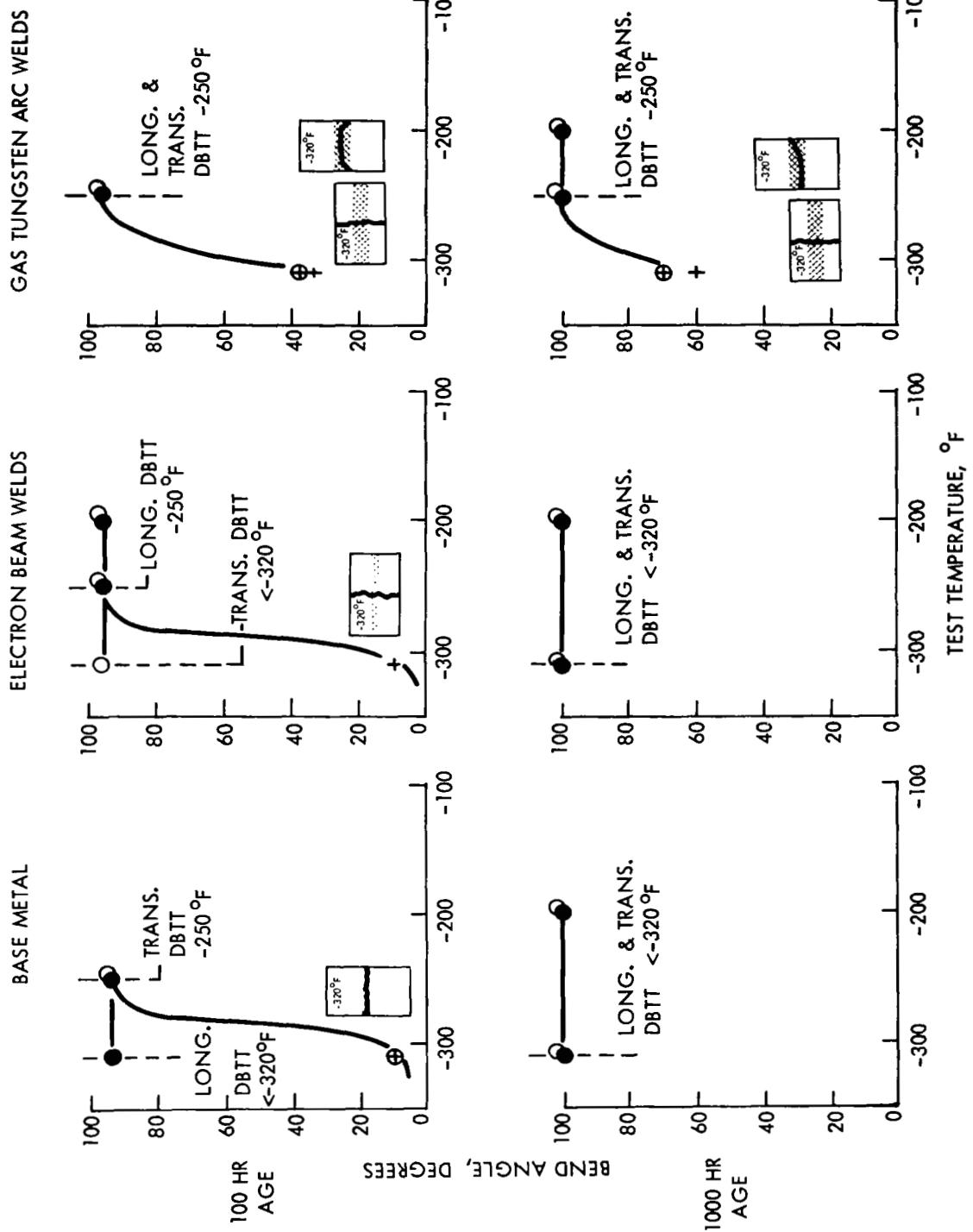
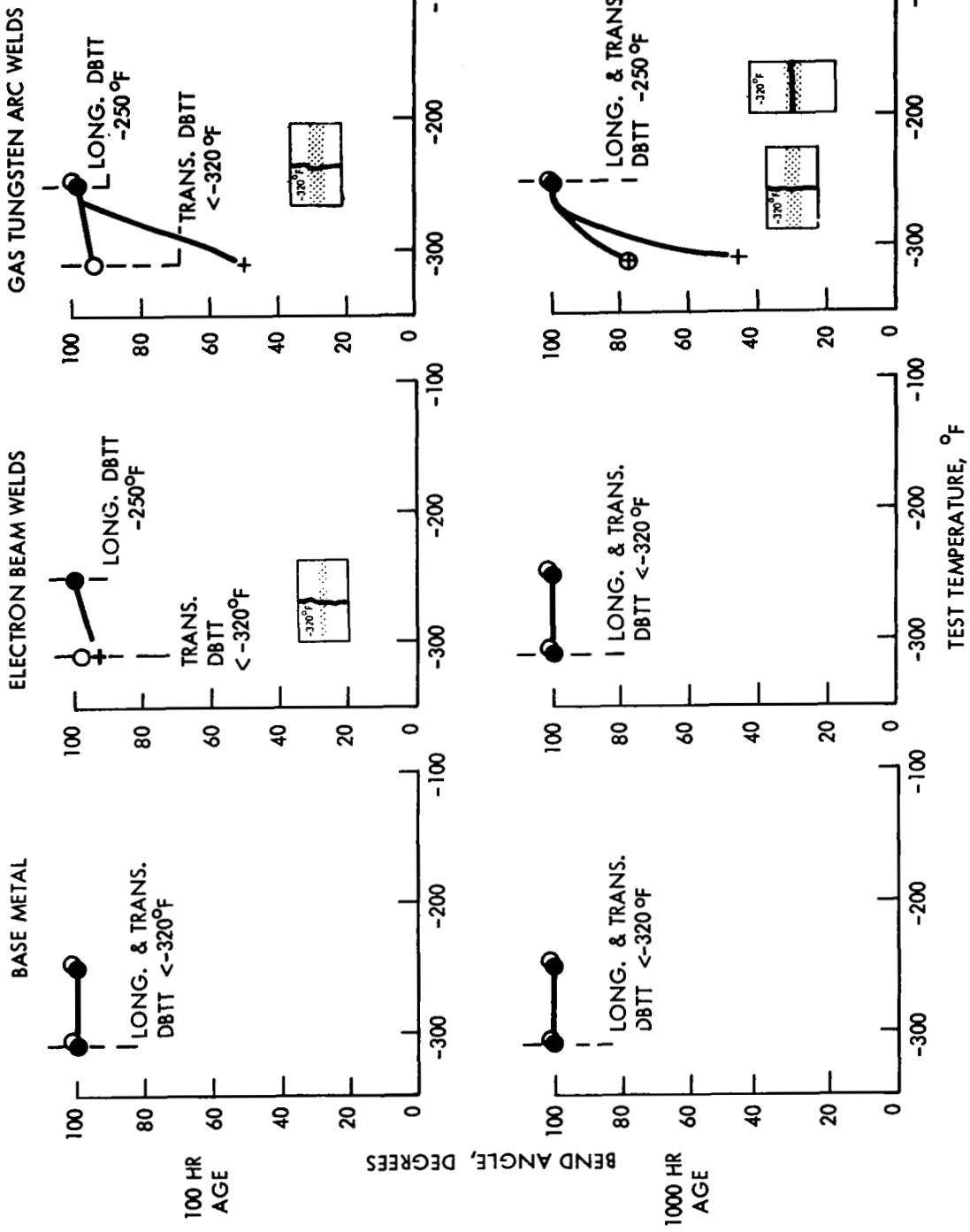
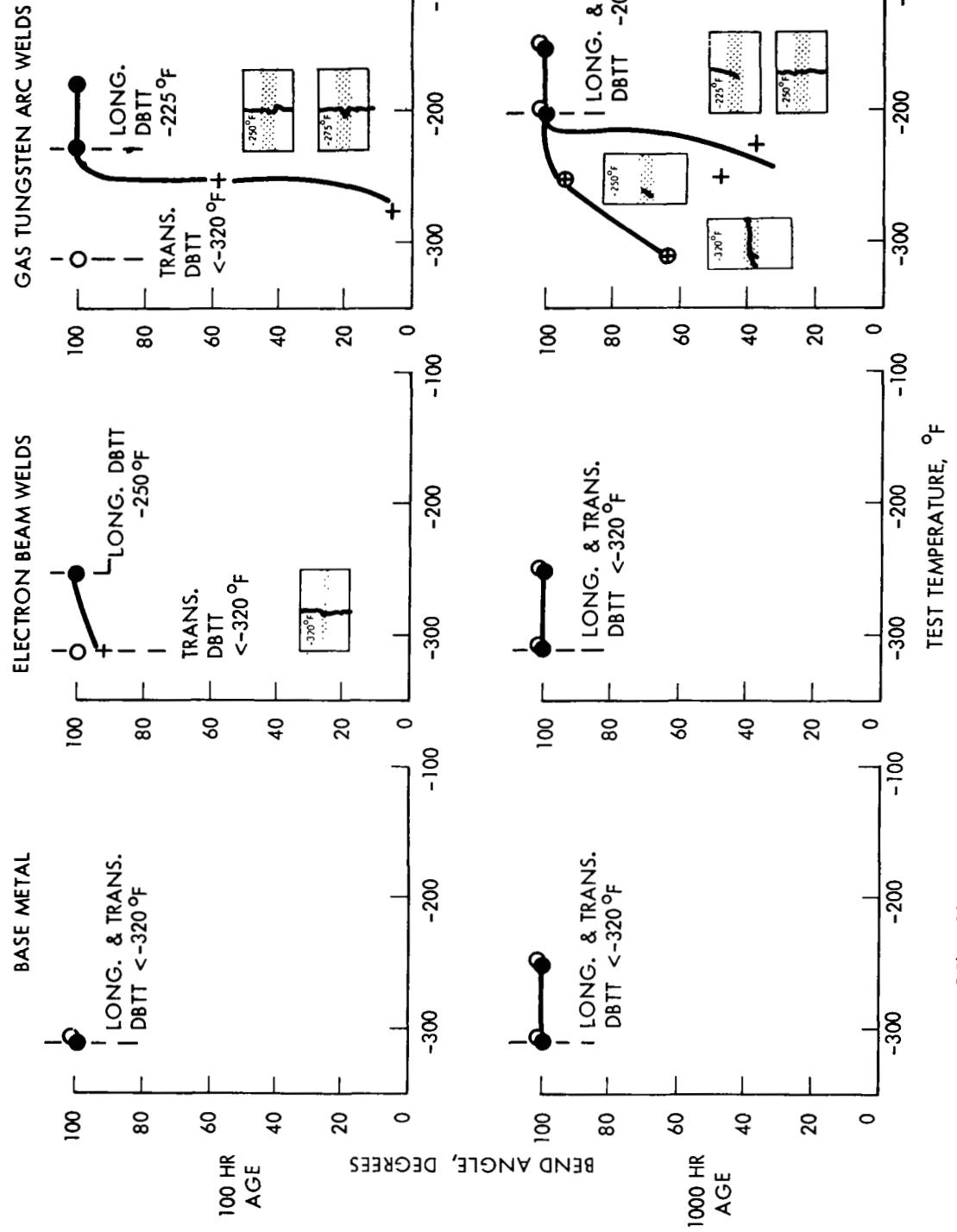


FIGURE A92 - Bend Ductile-Brittle Transition Temperature of SCb-291
As a Function of Aging Parameters (1t Bend Radius)

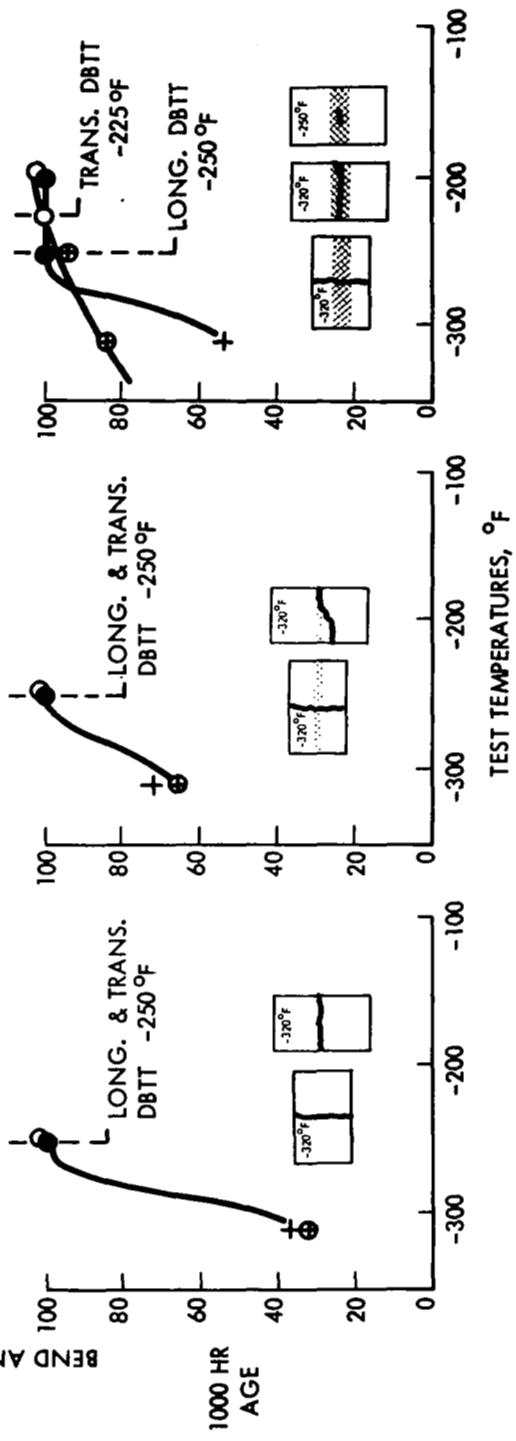
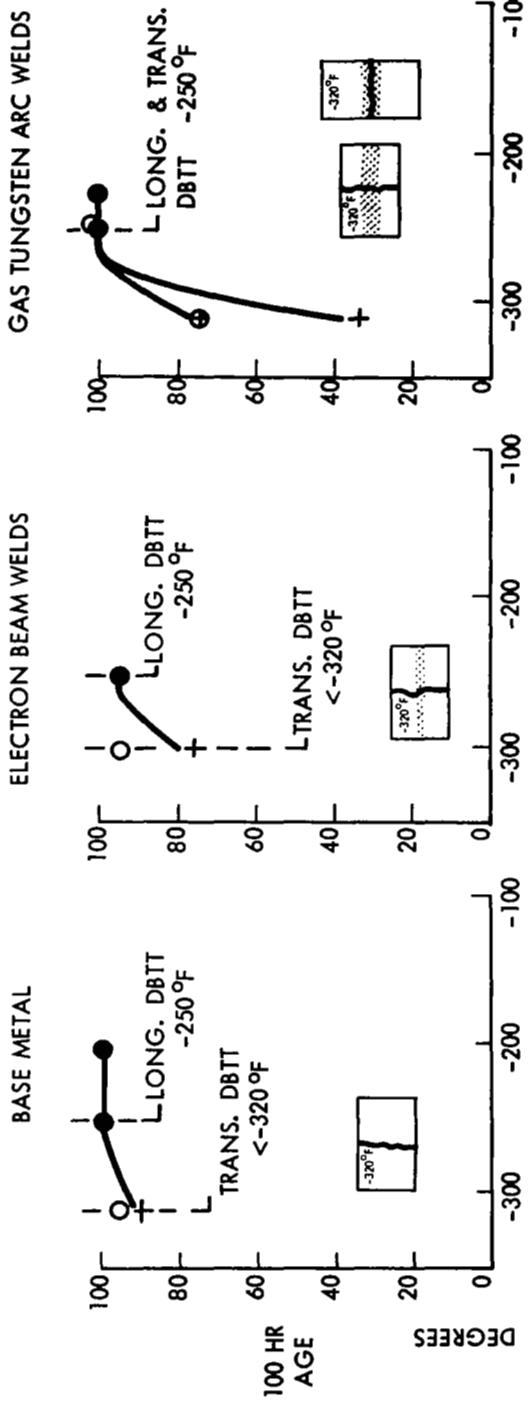






ALLOY: SCb - 291
AGING TEMP: 2100 °F

FIGURE A95 – Bend Test Results for SCb-291 Aged 100 and 1000 Hours at 2100°F
(1st Bend Radius)



ALLOY: SCb-291
AGING TEMP: 2400 °F

**FIGURE A96 - Bend Test Results for SCb-291 Aged 100 and 1000 Hours at 2400°F
(1† Bend Radius)**

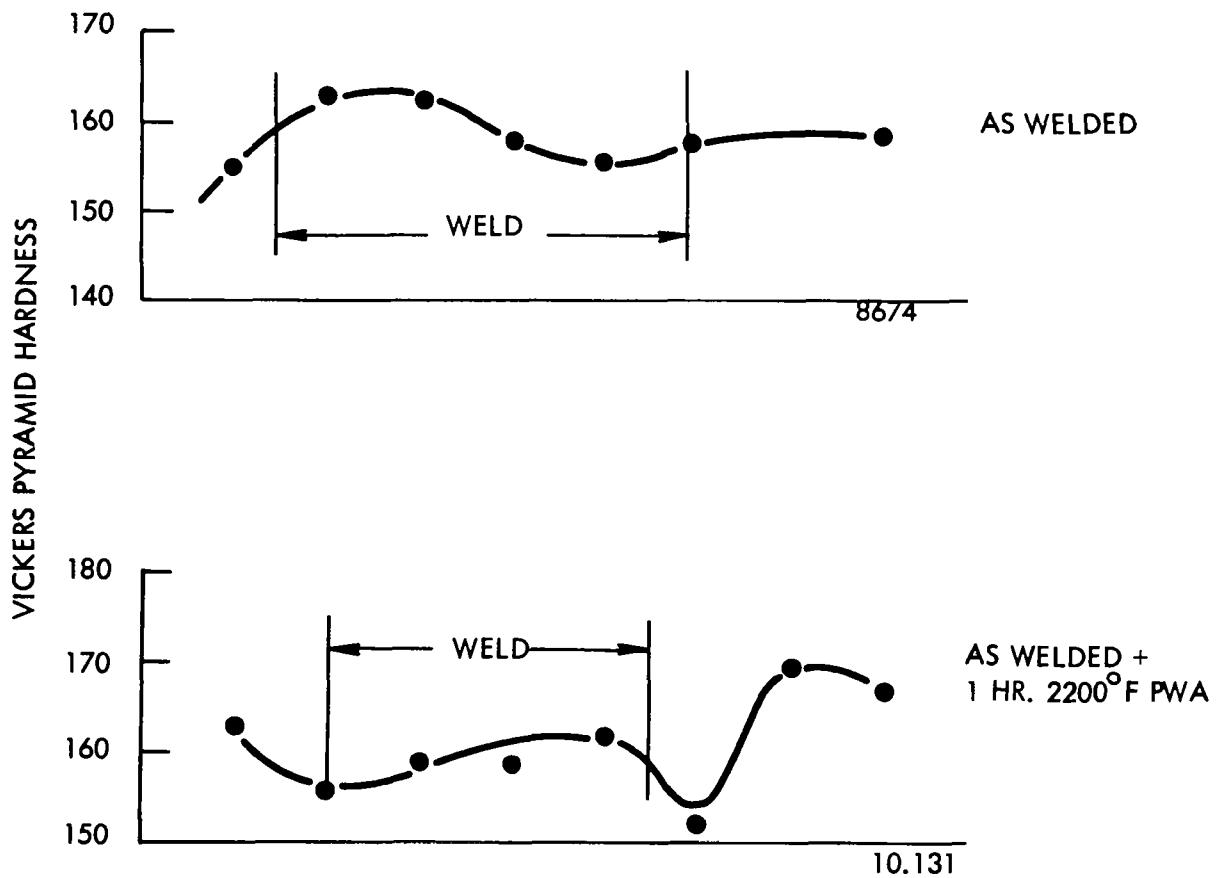
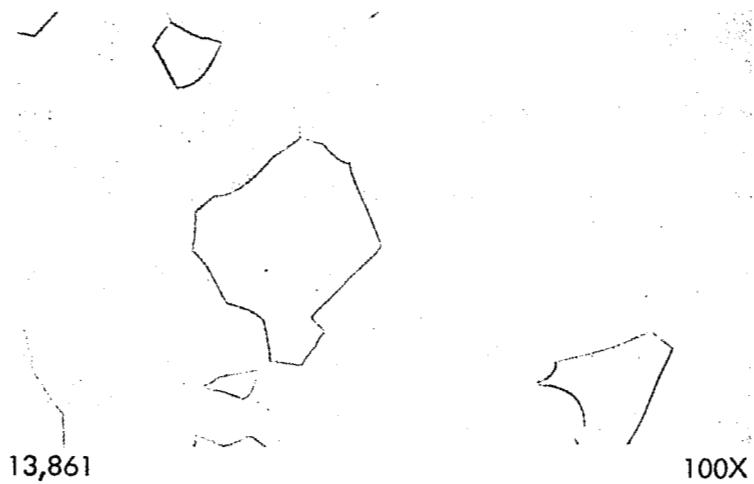


FIGURE A97 – Hardness Traverses for SCb-291 GTA Sheet Welds. Thermal History as Indicated. (10 Kg. Load on Vickers Hardness Tester.)



a) Base Metal of GTA Weld Specimen As Welded



b) Base Metal of GTA Weld Specimen After
1 Hr. -2200°F PWA + 1000 Hrs. -2400°F Age

FIGURE A98 - Microstructures of SCb-291 GTA Weld Specimens.
Thermal History as Indicated.

APPENDIX B - TENSILE DATA TABULATION FOR ALL ALLOYS

<u>Table</u>	<u>Title</u>	<u>Page No.</u>
B1	Tensile Properties of Unaged Sheet	153
B2	Sheet Tensile Properties for Base Metal and GTA Weld Specimens Aged 100 Hours in Ultra-High Vacuum Between 1500° F and 2400° F	156
B3	Sheet Tensile Properties for Base Metal and GTA Weld Specimens Aged 1000 Hours in Ultra-High Vacuum Between 1500° F and 2400° F	159
B4	Sheet Tensile Properties for Base Metal and GTA Weld Specimens Aged 5000 Hours in Ultra-High Vacuum Between 1500° F and 2400° F	162
B5	Sheet Tensile Properties for Base Metal and GTA Weld Specimens Aged 10,000 Hours in Ultra-High Vacuum Between 1500° F and 2400° F	163

TABLE B1 - Tensile Properties of Unaged Sheet

Alloy	Test Temp. (°F)	Specimen Type	Pre-Test 1 Hr. Anneal Temp. (°F)	Ultimate Strength psi x 10 ⁻³	0.2% Offset Yield Strength psi x 10 ⁻³	Elongation (%)	Weld Joint Efficiency (%)	Fracture Location
Ta-10W	R. T.	Base	None	84.4	71.5	29	--	--
	R. T.	Weld	None	81.4	69.9	9	97	Weld
	1800	Base	None	42.3	24.5	33	--	--
	1800	Weld	None	38.2	23.9	8	90	Weld
	2100	Base	None	33.7	17.6	42	--	--
	2100	Weld	None	29.5	19.7	5	88	Weld
	2400	Base	None	25.3	20.9	67	--	--
	2400	Weld	None	22.8	14.6	4	90	Weld
	T-111	R. T.	Base	2400	89.2	83.2	16	--
		R. T.	Weld	2400	92.0	82.5	14	102
		1800	Base	2400	61.3	34.6	14	--
		1800	Weld	2400	58.2	32.3	10	95
		2100	Base	2400	52.2	29.2	20	--
		2100	Weld	2400	49.0	30.2	14	94
		2400	Base	2400	38.9	23.4	32	--
		2400	Weld	2400	37.7	23.9	10	97
		T-222	R. T.	Base	2400	88.0	80.1	18
			R. T.	Weld	2400	90.1	83.2	14
			1800	Base	2400	62.8	33.9	10
			1800	Weld	2400	60.3	36.0	6
			2100	Base	2400	57.3	31.8	14
			2100	Weld	2400	52.7	32.9	7
			2400	Base	2400	39.9	27.9	20
			2400	Weld	2400	40.9	28.7	12
							102	Weld

•NOTE: Weld specimen surfaces ground flat and parallel to avoid surface contour effects providing a truer metallurgical joint efficiency.

TABLE B1 (Continued) - Tensile Properties of Unaged Sheet

Alloy	Test Temp. (°F)	Specimen Type	Pre-Test 1 Hr. Anneal Temp. (°F)	Ultimate Strength psi x 10 ⁻³	0.2% Offset Yield Strength psi x 10 ⁻³	Elongation (%)	Weld Joint Efficiency (%)	Fracture Location
D-43	R. T.	Base	2400	90.21	62.15	19.5	--	--
	R. T.	Weld	2400	90.26	63.75	18.0	100	Base
	1800	Base	2400	54.9	39.0	14	--	--
	1800	Weld	2400	55.6	42.1	8	101	Weld
	2100	Base	2400	43.3	33.7	16	--	
	2100	Weld	2400	43.6	38.6	9	100	Weld
	2400	Base	2400	32.7	24.7	21	--	
	2400	Weld	2400	32.6	27.7	6	100	Weld
	R. T.	Base	2200	59.57	47.53	23.5	--	--
	R. T.	Weld	2200	57.20	45.90	9	96	Weld
SCb-291	1800	Base	2200	20.9	12.3	46	--	--
	1800	Weld	2200	20.4	12.1	15	98	Weld
	2100	Base	2200	14.8	8.0	46	--	--
	2100	Weld	2200	16.0	10.8	43	108	Base
	2400	Base	2200	12.7	7.7	68	--	--
	2400	Weld	2200	12.6	7.5	50	99	Base
	R. T.	Base	2400	83.10	67.60	22.5	--	
	R. T.	Weld	2400	78.60	61.90	10	95	Weld
	1800	Base	2400	44.6	21.7	20	--	--
	1800	Weld	2400	40.4	22.1	8	90	Weld
FS-85	2100	Base	2400	34.5	21.9	30	--	--
	2100	Weld	2400	33.1	20.6	8	96	Weld
	2400	Base	2400	22.7	15.0	51	--	--
	2400	Weld	2400	23.4	15.4	12	102	Weld

* NOTE: Weld specimen surfaces ground flat and parallel to avoid surface contour effects providing a truer metallurgical joint efficiency.

TABLE B1 (Continued) - Tensile Properties of Unaged Sheet

Alloy	Test Temp. (°F)	Specimen Type	Pre-Test 1 Hr. Anneal Temp. (°F)	Ultimate Strength psi x 10 ⁻³	0.2% Offset Yield Strength psi x 10 ⁻³	Elongation (%)	Weld Joint Efficiency (%)	Fracture Location
B-66	R. T.	Base	None	104.73	79.88	22.5	--	--
	R. T.	Weld	None	100.92	81.04	9	97	Weld
	1800	Base	None	66.9	39.0	48	--	--
	1800	Weld	None	61.5	43.5	6	92	Weld
	2100	Base	None	39.7	29.1	69	--	--
	2100	Weld	None	42.3	33.2	13	103	Weld
	2400	Base	None	23.1	21.1	106	--	--
	2400	Weld	None	22.8	20.0	67	99	Base
C-129Y	R. T.	Base	2400	85.97	72.06	26.5	--	--
	R. T.	Weld	2400	74.93	66.54	5.5	87	Weld
	1800	Base	2400	51.7	31.8	27	--	--
	1800	Weld	2400	45.9	30.2	7	89	Weld
	2100	Base	2400	37.6	25.7	26	--	--
	2100	Weld	2400	36.6	28.8	6	98	Weld
	2400	Base	2400	24.7	20.1	84	--	--
	2400	Weld	2400	24.6	20.0	8	100	Weld
Cb-752	R. T.	Base	2200	73.10	55.50	27	--	--
	R. T.	Weld	2200	64.80	48.80	12.5	89	Weld
	1800	Base	2200	47.1	27.1	24	--	--
	1800	Weld	2200	50.6	28.2	13	104	Weld
	2100	Base	2200	34.6	22.6	40	--	--
	2100	Weld	2200	36.6	24.6	36	103	Base
	2400	Base	2200	22.7	15.6	72	--	--
	2400	Weld	2200	23.7	19.7	66	102	Base

*NOTE: Weld specimen surfaces ground flat and parallel to avoid surface contour effects providing a truer metallurgical joint efficiency.

TABLE B2 - Summary of Sheet Tensile Properties for Transverse Base Metal and Gas Tungsten Arc Weld Specimens Aged 100 Hours in Ultra-High Vacuum Between 1500°F and 2400°F

Alloy	Specimen Type	Test Temp. (°F)	Tensile Properties: Strength x 10 ⁻³ psi, Elongation in Percent						2400°F Age				
			1500°F Age			1800°F Age			2100°F Age				
			σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	σ_u		
B-66	Base	75	104.47	81.85	23.4	--	102.59	72.89	22.0	HAZ	100.6	71.7	
	Weld	75	100.95	81.2	9.0	HAZ	96.31	79.4	10.0	HAZ	94.6	72.5	
	Base	1800	67.5	43.6	31.0	--	--	--	--	Weld	67.5	42.0	
	Weld	1800	--	--	--	--	63.3	44.0	6.0	Weld	--	--	
	Base	2100	--	--	--	--	41.2	35.0	65.0	--	--	--	
	Weld	2100	40.5	34.4	10.0	Weld	--	--	--	41.2	34.3	13.0	
	Base	2400	27.1	26.2	70.0	--	--	--	--	26.2	25.3	97.0	
	Weld	2400	--	--	--	--	25.8	24.8	53.0	Base	--	--	
D-43	Base	75	98.89	60.48	19.5	--	98.97	57.73	20.5	--	86.19	55.09	
	Weld	75	87.46	60.79	19.0	Base	86.52	64.01	17.5	Base	86.35	55.87	
	Base	1800	55.6	42.8	14.0	--	--	--	--	53.5	41.1	15.0	
	Weld	1800	--	--	--	--	51.5	43.0	12.0	Base	--	--	
	Base	2100	--	--	--	--	44.8	38.6	16.0	--	--	--	
	Weld	2100	44.2	39.6	17.0	Base	--	--	--	41.1	35.8	17.0	
	Base	2400	32.8	28.7	23.0	--	--	33.4	29.5	8.0	HAZ	--	--
	Weld	2400	--	--	--	--	--	--	--	31.0	24.9	26.0	
FS-85	Base	75	B3.47	61.93	25.5	--	76.94	58.56	9.0	--	81.1	52.09	
	Weld	75	77.91	62.33	7.0	HAZ	81.76	59.56	25.0	Weld	77.61	51.5	
	Base	1800	44.6	25.0	21.0	--	--	--	--	41.8	23.9	27.0	
	Weld	1800	--	--	--	--	39.1	25.8	7.0	HAZ	--	--	
	Base	2100	--	--	--	--	32.6	21.7	38.0	--	--	--	
	Weld	2100	32.6	23.4	8.0	Weld	--	--	--	31.5	22.7	9.0	
	Base	2400	22.9	17.3	77.0	--	--	--	--	23.6	18.3	51.0	
	Weld	2400	--	--	--	--	23.4	18.0	9.0	Weld	--	--	

NOTES: All data based on welds prepared using optimum welding conditions and post weld anneals. Base metal annealed with same anneal as GTA welds.

TABLE B2(Continued) - Summary of Sheet Tensile Properties for Transverse Base Metal and Gas Tungsten Arc Weld Specimens Aged 100 Hours in Ultra-High Vacuum Between 1500°F and 2400°F

Alloy	Specimen Type	Temp. (°F)	1500°F Age						1800°F Age						2100°F Age						2400°F Age																			
			Strength			Elong.			Failure Location			Strength			Elong.			Failure Location			Strength			Elong.			Failure Location													
			σ _u	σ _y	Elong.	σ _u	σ _y	Elong.	HAZ	HAZ	Weld	σ _u	σ _y	Elong.	HAZ	HAZ	Weld	σ _u	σ _y	Elong.	HAZ	HAZ	Weld	σ _u	σ _y	Elong.	HAZ	HAZ	Weld											
T-11	Base	75	87.08	80.82	20.0	--	86.26	75.48	19.0	--	85.3	74.18	19.0	--	84.18	77.38	19.0	--	85.6	74.55	18.0	--	84.18	77.38	19.0	--	85.6	74.55	18.0	HAZ	HAZ	HAZ								
	Weld	75	88.52	79.42	12.5	HAZ	88.89	77.21	14.0	HAZ	86.25	76.89	13.0	HAZ	85.6	74.55	18.0	HAZ	85.6	74.55	18.0	HAZ	85.6	74.55	18.0	HAZ	85.6	74.55	18.0	HAZ	HAZ	HAZ								
	Base	1800	60.2	38.6	15.0	--	--	--	--	Weld	54.0	30.6	15.0	--	--	--	--	52.7	32.7	9.0	Weld	50.9	29.0	23.0	--	--	--	--	--	--	--	--	--	--	--					
	Weld	1800	--	--	--	--	--	--	Weld	--	--	--	--	--	--	--	--	50.9	29.0	23.0	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--					
	Base	2100	--	--	--	--	--	--	Weld	51.5	31.4	23.0	--	--	--	--	45.7	31.3	10.0	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--					
	Weld	2100	51.3	31.9	16.0	HAZ	--	--	--	Weld	--	--	--	--	--	--	--	38.7	25.9	37.0	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--					
	Base	2400	38.7	27.2	45.0	--	--	--	Weld	28.0	11.0	Weld	--	--	--	--	--	--	--	36.2	26.4	7.0	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--				
	Weld	2400	--	--	--	--	--	--	Weld	38.7	28.0	11.0	Weld	--	--	--	--	--	--	--	36.2	26.4	7.0	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--			
	Base	75	81.2	71.85	24.5	--	82.5	74.31	25.0	--	94.14	77.9	29.5	--	80.21	70.87	25.5	--	74.35	64.0	8.5	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--					
	Weld	75	79.21	68.97	10.0	Weld	67.39	77.2	9.0	Weld	74.88	62.08	10.5	Weld	--	--	--	41.7	24.7	34.0	--	--	--	--	--	--	--	--	--	--	--	--	--							
Ta-10W	Base	1800	41.9	26.0	36.0	--	--	--	Weld	24.1	8.0	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--						
	Weld	1800	--	--	--	--	--	--	Weld	37.9	21.4	56.0	--	--	--	--	29.7	19.3	9.0	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--					
	Base	2100	--	--	--	--	--	--	Weld	32.9	21.4	56.0	--	--	--	--	26.4	15.8	60.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--					
	Weld	2100	28.2	23.0	5.0	Weld	--	--	--	Weld	--	--	--	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--						
	Base	2400	26.1	17.9	68.0	--	--	--	Weld	23.8	18.3	7.0	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--							
	Weld	2400	--	--	--	--	--	--	Weld	--	--	--	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--							
	Base	75	83.12	78.17	15.5	--	81.82	71.46	17.5	--	82.82	74.1	16.5	--	81.82	73.7	17.5	--	81.06	76.45	15.0	Base	81.06	76.45	15.0	Base	81.06	76.45	15.0	Base	81.06	76.45	15.0	Base	81.06	76.45	15.0			
	Weld	75	82.4	72.7	14.5	Base	81.94	73.07	12.5	Base	82.77	82.77	13.5	Base	--	--	--	54.5	32.3	13.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
	Base	1800	60.0	34.9	13.0	--	--	--	Weld	56.8	34.2	11.0	Base	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--				
	Weld	1800	--	--	--	--	--	--	Weld	50.8	31.6	17.0	--	--	--	--	49.7	34.2	10.0	Base	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
	Base	2100	--	--	--	HAZ	--	--	Weld	--	--	--	Weld	--	--	--	40.7	31.4	23.0	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
	Weld	2100	54.2	35.3	14.0	--	--	--	Weld	41.4	32.2	8.0	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--				
	Base	2400	40.2	30.0	26.0	--	--	--	Weld	--	--	--	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		
	Weld	2400	--	--	--	--	--	--	Weld	--	--	--	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
T-222	Base	75	83.12	78.17	15.5	--	81.82	71.46	17.5	--	82.82	74.1	16.5	--	81.82	73.7	17.5	--	81.06	76.45	15.0	Base	81.06	76.45	15.0	Base	81.06	76.45	15.0	Base	81.06	76.45	15.0	Base	81.06	76.45	15.0			
	Weld	75	82.4	72.7	14.5	Base	81.94	73.07	12.5	Base	82.77	82.77	13.5	Base	--	--	--	54.5	32.3	13.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		
	Base	1800	60.0	34.9	13.0	--	--	--	Weld	56.8	34.2	11.0	Base	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
	Weld	1800	--	--	--	--	--	--	Weld	50.8	31.6	17.0	--	--	--	--	49.7	34.2	10.0	Base	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
	Base	2100	--	--	--	HAZ	--	--	Weld	--	--	--	Weld	--	--	--	40.7	31.4	23.0	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
	Weld	2100	54.2	35.3	14.0	--	--	--	Weld	--	--	--	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		
	Base	2400	40.2	30.0	26.0	--	--	--	Weld	41.4	32.2	8.0	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
	Weld	2400	--	--	--	--	--	--	Weld	--	--	--	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Base	75	83.12	78.17	15.5	--	81.82	71.46	17.5	--	82.82	74.1	16.5	--	81.82	73.7	17.5	--	81.06	76.45	15.0	Base	81.06	76.45	15.0	Base	81.06	76.45	15.0	Base	81.06	76.45	15.0							
	Weld	75	82.4	72.7	14.5	Base	81.94	73.07	12.5	Base	82.77	82.77	13.5	Base	--	--	--	54.5	32.3	13.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
	Base	1800	60.0	34.9	13.0	--	--	--	Weld	56.8	34.2	11.0	Base	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
	Weld	1800	--	--	--	--	--	--	Weld	50.8	31.6	17.0	--	--	--	--	49.7	34.2	10.0	Base	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
	Base	2100	--	--	--	HAZ	--	--	Weld	--	--	--	Weld	--	--	--	40.7	31.4	23.0	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		
	Weld	2100	54.2	35.3	14.0	--	--	--	Weld	--	--	--	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Base	2400	40.2	30.0	26.0	--	--	--	Weld	--	--	--	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Weld	2400	--	--	--	--	--	--	Weld	--	--	--	Weld	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

NOTE: All data based on welds prepared using optimum welding conditions and post weld anneals. Base metal annealed with same anneal as GTA welds.

TABLE B2 (Continued) - Summary of Sheet Tensile Properties for Transverse Base Metal and Gas Tungsten Arc Weld Specimens Aged 100 Hours in Ultra-High Vacuum Between 1500°F and 2400°F

Alloy	Specimen Type	Test Temp. (°F)	Tensile Properties: Strength $\times 10^{-3}$ psi, Elongation in Percent												2400°F Age			
			1500°F Age				1800°F Age				2100°F Age				2400°F Age			
			σ _u	σ _y	Elong.	Failure Location	σ _u	σ _y	Elong.	Failure Location	σ _u	σ _y	Elong.	Failure Location	σ _u	σ _y	Elong.	Failure Location
Cb-752	Base	75	81.45	59.95	25.5	Weld	106.38	77.57	27.5	Weld	80.05	49.68	24.0	--	79.76	57.76	26.5	--
	Weld	75	82.75	60.98	16.0	Weld	61.14	44.46	13.5	Weld	79.13	52.25	13.0	Weld	79.89	59.73	12.0	Weld
	Base	1800	49.1	30.6	31.0	--	--	--	29.0	Base	47.7	36.0	--	--	49.5	27.8	15.0	Weld
	Weld	1800	--	--	--	--	47.5	24.0	--	Base	--	--	--	--	35.9	24.6	39.0	--
	Base	2100	--	--	--	--	32.8	24.4	67.0	--	--	--	--	--	--	--	--	--
	Weld	2100	35.7	25.7	41.0	Base	--	--	--	Base	34.6	24.1	44.0	Base	--	--	--	--
	Base	2400	23.0	20.0	125.0	--	--	--	20.6	Base	23.1	20.7	75.0	--	--	--	--	--
	Weld	2400	--	--	--	--	24.4	--	--	Base	--	--	--	--	24.9	20.0	55.0	Base
	Base	75	58.4	43.66	29.5	--	58.21	42.07	29.0	--	59.73	46.21	25.5	--	58.18	44.06	28.0	--
	Weld	75	56.43	45.42	9.0	Weld	56.36	44.42	10.5	Weld	57.02	46.59	9.5	Weld	52.83	41.41	9.0	Weld
SCb-291	Base	1800	20.2	13.3	49.0	--	--	--	--	Weld	20.6	13.2	47.0	--	--	--	--	--
	Weld	1800	--	--	--	--	20.5	14.7	12.0	Weld	--	--	--	--	19.9	12.0	13.0	Weld
	Base	2100	--	--	--	--	16.1	10.2	55.0	--	--	--	--	--	15.4	10.2	56.0	--
	Weld	2100	16.8	12.6	42.0	Base	--	--	--	Base	16.0	10.3	44.0	Weld	--	--	--	--
	Base	2400	12.3	8.2	71.0	--	--	--	--	Base	--	--	--	--	13.0	6.5	41.0	--
	Weld	2400	--	--	--	--	13.1	9.3	59.0	Base	--	--	--	--	--	--	12.6	7.5
	Base	75	87.12	70.04	28.0	--	86.13	67.84	24.0	--	86.91	69.41	27.0	--	86.63	68.75	26.5	--
	Weld	75	76.05	66.13	6.0	Weld	76.77	65.98	7.5	Weld	75.29	65.42	6.0	Weld	76.32	66.78	6.5	Weld
	Base	1800	52.1	31.8	25.0	--	--	--	--	Base	49.3	30.7	23.0	--	--	--	--	--
	Weld	1800	--	--	--	--	44.1	30.3	8.0	Weld	--	--	--	--	45.7	30.2	8.0	Weld
C-129Y	Base	2100	--	--	--	--	37.4	26.2	33.0	--	--	--	--	--	39.4	27.8	19.0	--
	Weld	2100	36.3	27.2	7.0	Weld	--	--	--	Weld	34.2	24.9	10.0	Weld	--	--	--	--
	Base	2400	24.9	22.6	76.0	--	--	--	--	Base	23.6	21.2	92.0	--	--	--	--	--
	Weld	2400	--	--	--	--	24.8	22.0	18.0	Weld	--	--	--	--	25.8	21.8	19.0	Weld

NOTE: All data based on welds prepared using optimum welding conditions and post weld anneals. Base metal annealed with same anneal as GTA welds.

TABLE B3 - Summary of Sheet Tensile Properties for Transverse Base Metal and Gas Tungsten Arc Weld Specimens Aged 1000 Hours in Ultra-High Vacuum Between 1500°F and 2400°F

Alloy	Specimen Type	Temp. (°F)	Tensile Properties: Strength $\times 10^{-3}$ psi, Elongation in percent												Failure Location					
			1500°F Age				1800°F Age				2100°F Age									
			σ _u	σ _y	Elong.	Failure Location	σ _u	σ _y	Elong.	Failure Location	σ _u	σ _y	Elong.	Failure Location						
B-66	Base	75	101.5	82.4	21.5	--	102.5	77.9	21.5	--	103.0	74.8	22.5	--	97.6	74.1	20.5	--	Weld	
	Weld	75	102.4	82.6	12.0	HAZ	101.6	78.4	13.0	Weld	97.0	73.4	12.5	--	97.1	73.8	16.0	--	Weld	
	Base	1800	--	--	--	HAZ	65.0	39.9	41.0	--	--	--	43.2	9.0	Weld	62.7	40.9	20.0	--	--
	Weld	1800	65.3	47.4	6.0	Weld	--	--	--	Weld	65.2	43.2	9.0	--	--	--	--	--	--	--
	Base	2100	40.0	35.4	58.0	--	--	--	Base	44.3	35.0	56.0	--	--	--	--	--	--	--	--
	Weld	2100	--	--	--	HAZ	40.3	33.8	49.0	Base	--	--	--	--	--	--	--	--	--	--
	Base	2400	--	--	--	HAZ	24.4	23.4	109.0	--	--	27.9	25.3	19.0	Weld	28.8	27.3	31.0	--	Weld
	Weld	2400	26.0	24.2	44.0	--	--	--	Base	--	--	--	--	--	--	45.8	37.8	6.0	--	Weld
D-43	Base	75	91.0	62.5	19.5	--	88.9	53.5	17.0	--	85.4	57.7	21.0	--	76.6	52.2	22.0	--	Weld	
	Weld	75	89.8	61.8	18.0	Base	87.1	56.2	18.0	Base	83.1	54.2	19.0	Base	74.3	48.0	14.0	--	Weld	
	Base	1800	--	--	--	HAZ	49.7	41.1	15.0	--	--	--	--	--	44.8	31.9	16.0	--	--	
	Weld	1800	56.3	44.3	13.0	Weld	--	--	--	Weld	47.5	37.3	14.0	Base	--	--	--	--	--	
	Base	2100	44.1	39.3	16.0	--	--	--	Base	38.9	33.5	29.0	--	--	--	--	--	--	--	
	Weld	2100	--	--	--	HAZ	42.0	37.2	18.0	Base	--	--	--	--	--	32.4	25.4	14.0	--	Weld
	Base	2400	--	--	--	HAZ	32.9	28.6	21.0	--	--	--	--	--	25.5	20.6	28.0	--	--	
	Weld	2400	32.3	28.5	7.0	Weld	--	--	--	Weld	--	29.2	24.7	13.0	HAZ	--	--	--	--	--
FS-85	Base	75	76.6	56.3	24.5	--	81.5	60.3	26.0	--	81.9	59.1	26.0	--	80.9	61.3	25.0	--	Weld	
	Weld	75	79.9	62.3	10.0	Weld	55.1	BF*	0.05	Base	76.5	62.3	8.0	Weld	77.6	60.1	11.5	--	HAZ	
	Base	1800	--	--	--	HAZ	41.8	24.8	24.0	--	--	--	--	--	43.3	23.6	18.0	--	--	
	Weld	1800	41.4	25.4	8.0	--	--	--	Weld	39.4	25.4	9.0	HAZ	--	--	--	--	--	--	
	Base	2100	33.0	21.2	35.0	--	--	--	Weld	31.2	22.0	8.0	--	--	--	30.1	20.6	52.0	--	--
	Weld	2100	--	--	--	HAZ	--	--	--	Weld	--	--	--	--	--	32.4	21.1	9.0	--	HAZ
	Base	2400	--	--	--	HAZ	22.8	17.3	55.0	--	--	24.0	17.9	12.0	Weld	24.1	17.8	47.0	--	--
	Weld	2400	23.2	17.1	10.0	Weld	--	--	--	Weld	--	--	--	--	--	--	--	--	--	--
Cb-752	Base	75	81.9	59.6	23.5	--	80.1	58.4	25.5	--	80.8	59.5	30.0	--	79.8	57.1	24.0	--	Weld	
	Weld	75	84.3	57.1	18.0	Weld	80.6	60.3	14.0	Weld	82.4	61.0	16.0	Weld	78.8	50.6	13.0	--	Weld	
	Base	1800	--	--	--	Weld	45.5	27.9	31.0	--	--	--	--	--	47.0	25.3	18.0	--	--	
	Weld	1800	47.0	29.0	23.0	Base	--	--	--	Weld	46.7	26.7	23.0	Weld	--	--	--	--	--	
	Base	2100	34.2	24.4	58.0	--	--	--	Base	34.2	24.0	61.0	--	--	--	34.9	23.8	23.0	--	HAZ
	Weld	2100	--	--	--	HAZ	--	--	--	Weld	--	--	--	--	--	23.5	19.7	54.0	--	--
	Base	2400	--	--	--	HAZ	--	--	--	Weld	22.3	19.1	122.0	--	--	23.3	20.1	73.0	Base	--
	Weld	2400	23.9	19.4	62.0	Base	--	--	--	Weld	--	--	--	--	--	--	--	--	--	--

NOTE: All data based on welds prepared using optimum welding conditions and post-weld anneals. Base metal annealed with same anneal as GTAW welds.

*Brittle Fracture

TABLE B3 (Continued) - Summary of Sheet Tensile Properties for Transverse Base Metal and Gas-Tungsten Arc Weld Specimens Aged 1000 Hours in Ultra-High Vacuum Between 1500°F and 2400°F

Alloy	Specimen Type	Test Temp. (°F)	Tensile Properties: Strength $\times 10^{-3}$ psi, Elongation in percent																
			1500°F Age				1800°F Age				2100°F Age				2400°F Age				
			σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	
SCb-291	Base	75	50.6	45.0	30.0	--	60.2	46.8	24.5	--	59.8	44.9	29.0	--	60.5	47.7	23.0	--	
	Weld	75	56.7	45.4	10.5	Weld	54.1	42.4	8.0	Weld	55.2	43.6	8.5	Weld	52.2	38.8	9.5	Weld	
	Base	1800	--	--	--	Weld	20.2	11.8	50.0	--	20.4	11.7	14.0	Weld	17.9	10.7	29.0	--	
	Weld	1800	20.9	14.3	12.0	Weld	--	--	--	Weld	15.7	10.0	57.0	--	--	--	--	--	
	Base	2100	16.0	10.2	44.0	--	--	15.9	9.8	23.0	Weld	--	--	--	14.7	9.3	30.0	Weld	
	Weld	2100	--	--	--	Weld	--	13.5	8.9	32.0	--	--	--	--	12.4	8.0	45.0	--	
	Base	2400	--	--	--	Weld	--	--	--	Weld	--	--	--	Base	--	--	--	--	
	Weld	2400	12.3	8.7	35.0	Weld	--	--	--	Weld	13.2	8.5	43.0	--	--	--	--	--	
	Base	75	86.4	69.9	26.5	--	86.9	68.6	28.5	--	86.8	68.1	27.0	--	86.2	66.7	27.0	--	
	Weld	75	76.5	67.0	7.0	Weld	77.4	67.4	6.5	Weld	75.5	65.6	6.0	Weld	75.2	64.6	7.0	HAZ	
C-129Y	Base	1800	--	--	--	Weld	49.4	29.8	25.0	--	--	--	--	Weld	50.9	28.3	23.0	--	
	Weld	1800	45.7	29.9	8.0	Weld	--	--	--	Weld	43.8	29.3	9.0	Weld	--	--	--	--	
	Base	2100	35.8	26.0	35.0	--	--	35.3	24.8	10.0	Weld	--	--	--	Weld	38.8	26.2	19.0	--
	Weld	2100	--	--	--	Weld	--	24.3	22.2	71.0	--	--	--	Weld	--	--	--	--	
	Base	2400	--	--	--	Weld	--	--	--	Weld	--	--	--	Base	25.5	21.8	19.0	Weld	
	Weld	2400	24.2	20.8	23.0	Weld	--	--	--	Weld	23.9	21.2	53.0	--	--	--	--	--	
	Base	75	87.4	77.3	19.5	--	86.7	73.7	17.0	--	84.2	72.7	19.0	--	83.4	75.3	18.0	--	
	Weld	75	87.0	76.9	11.5	HAZ	86.0	75.2	10.5	Weld	82.8	71.6	10.0	Weld	84.3	74.2	14.0	HAZ	
	Base	1800	--	--	--	Weld	54.9	33.4	15.0	--	--	--	--	Weld	54.8	31.0	15.0	--	
	Weld	1800	55.3	38.5	9.0	Weld	--	--	--	Weld	49.8	31.9	8.0	Weld	--	--	--	--	
T-111	Base	2100	49.9	30.4	27.0	--	--	--	HAZ	47.9	28.6	27.0	--	--	--	--	--	--	
	Weld	2100	--	--	--	Weld	--	47.1	30.3	12.0	HAZ	--	--	--	Weld	45.1	27.7	12.0	HAZ
	Base	2400	--	--	--	Weld	--	39.1	26.8	42.0	--	--	--	Weld	37.9	25.6	38.0	--	
	Weld	2400	37.6	28.2	9.0	Weld	--	--	--	Weld	36.3	27.1	7.0	Weld	--	--	--	--	

NOTE: All data based on welds prepared using optimum welding conditions and post weld anneals. Base metal annealed with same anneal as GTA welds.

TABLE B3 (Continued) - Summary of Sheet Tensile Properties for Transverse Base Metal and Gas Tungsten Arc Weld Specimens Aged 1000 Hours in Ultra-High Vacuum Between 1500°F and 2400°F

Alloy	Specimen Type	Temp. (F)	Tensile Properties: Strength $\times 10^{-3}$ psi, Elongation in Percent															
			1500°F Age				1800°F Age				2100°F Age				2400°F Age			
			σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location
Ta-10W	Base	75	83.4	69.2	28.0	--	80.5	67.6	25.5	--	82.7	69.5	27.0	--	78.1	67.0	25.5	--
	Weld	75	80.9	71.0	7.0	Weld	78.5	67.7	10.5	Weld	74.6	63.9	8.5	Weld	75.6	63.1	12.0	Weld
	Base	1800	--	--	--	41.4	25.0	37.0	--	--	--	--	--	Weld	37.2	20.1	39.0	--
	Weld	1800	37.5	24.2	7.0	Weld	--	--	--	--	39.0	25.4	11.0	Weld	--	--	--	--
	Base	2100	32.8	20.0	50.0	--	--	--	--	--	33.2	20.5	47.0	--	--	--	--	--
	Weld	2100	--	--	--	--	32.2	21.6	11.0	Weld	--	--	--	--	27.4	19.4	9.0	Weld
	Base	2400	--	--	--	26.6	17.5	60.0	--	--	--	--	--	26.6	16.4	42.0	--	
	Weld	2400	22.8	17.1	5.0	Weld	--	--	--	--	23.8	17.1	8.0	Weld	--	--	--	--
T-222	Base	75	83.4	72.4	16.0	--	82.1	72.2	17.0	--	83.2	71.1	14.0	--	82.0	70.8	16.5	--
	Weld	75	82.0	72.8	18.0	Base	84.4	75.2	11.5	Weld	83.4	72.0	14.0	Base	81.3	68.8	16.0	Base
	Base	1800	--	--	--	51.8	31.9	13.0	--	--	--	--	--	54.3	31.9	13.0	--	
	Weld	1800	60.5	35.3	10.0	HAZ	--	--	--	--	53.8	33.8	10.0	HAZ	--	--	--	--
	Base	2100	53.8	32.4	15.0	--	--	--	--	--	47.4	31.2	18.0	--	--	--	--	--
	Weld	2100	--	--	--	--	51.4	33.8	12.0	Base	--	--	--	--	47.7	30.5	13.0	HAZ
	Base	2400	--	--	--	39.9	31.2	27.0	--	--	41.2	32.2	12.0	HAZ	--	38.4	28.1	24.0
	Weld	2400	41.7	32.0	10.0	HAZ	--	--	--	--	--	--	--	--	--	--	--	--

NOTES: All data based on welds prepared using optimum welding conditions and post weld anneals. Base metal annealed with same anneal as GTA welds.

TABLE B4 - Summary of Sheet Tensile Properties for Transverse Base Metal and Gas Tungsten Arc Weld Specimens Aged 5000 Hours in Ultra High Vacuum Between 1500°F and 2400°F

Alloy	Specimen Type	Test Temp. (°F)	1500°F Age				1800°F Age				2100°F Age				2400°F Age							
			σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location				
B-66	Base	75	103.6	79.6	22.0	---	101.5	77.3	23.0	---	100.7	73.0	24.5	---	---	---	---	---				
	Weld	75	100.7	82.4	11.5	W	95.6	75.8	11.5	W	97.6	73.9	13.0	W	---	---	---	---				
	Base	1800	68.2	45.6	25.0	---	---	40.9	41.9	7.0	W	68.0	41.0	30.0	---	---	---	---	---			
	Weld	1800	---	---	---	---	40.9	33.6	60.0	---	---	---	---	---	---	---	---	---	---			
	Base	2100	42.4	35.3	10.0	W	---	---	---	---	46.8	34.2	13.0	W	---	---	---	---	---			
	Weld	2100	25.8	24.4	168.0	---	---	27.1	24.3	27.0	W	27.8	24.8	70.0	---	---	---	---	---			
	Base	2400	---	---	---	---	81.9	61.1	21.5	---	82.2	61.8	23.0	---	---	---	---	---	---			
	Weld	75	82.6	67.0	6.5	W	75.8	58.9	9.0	HAZ	79.7	59.0	23.5	---	77.5	57.0	21.5	---	---			
	Base	1800	44.7	25.4	18.0	---	---	39.7	21.8	7.0	HAZ	74.8	57.0	9.0	HAZ	54.8	43.7	10.0	HAZ	---		
	Weld	1800	---	---	---	---	32.6	22.2	42.0	---	40.7	22.9	26.0	---	40.7	21.6	10.0	HAZ	---	---		
FS-85	Base	2100	---	---	---	---	23.6	22.0	8.0	W	---	---	---	---	30.8	16.5	12.0	W	34.0	29.0	---	---
	Weld	2100	82.0	67.0	59.0	---	58.7	59.0	---	---	23.3	15.8	67.0	---	23.3	15.8	67.0	---	25.5	21.5	---	---
	Base	2400	---	---	---	---	25.0	16.1	10.0	W	---	---	---	---	40.7	22.9	26.0	---	40.7	21.6	10.0	HAZ
	Weld	2400	---	---	---	---	85.6	73.3	16.5	---	82.5	71.9	20.0	---	82.5	69.4	16.5	---	82.5	71.3	15.5	HAZ
	Base	75	87.8	76.0	20.0	---	85.2	73.5	11.0	W	83.0	70.6	11.5	HAZ	54.0	30.3	17.0	---	54.0	30.3	17.0	---
	Weld	75	85.3	75.6	9.5	W	85.2	73.5	11.0	W	83.0	70.6	11.5	HAZ	44.5	26.8	9.0	W	48.3	27.7	21.0	---
	Base	1800	58.7	37.5	15.0	---	49.8	32.6	9.0	HAZ	37.6	22.9	47.0	---	37.6	22.9	47.0	---	37.6	22.9	47.0	---
	Weld	1800	---	---	---	---	49.1	29.4	25.0	---	54.0	30.3	17.0	---	54.0	30.3	17.0	---	54.0	30.3	17.0	---
	Base	2100	49.2	31.5	11.0	HAZ	---	---	---	---	44.5	26.8	9.0	W	---	---	---	---	44.5	26.8	9.0	W
	Weld	2100	40.0	26.1	39.0	---	37.4	26.0	8.0	W	48.3	30.3	17.0	---	48.3	27.7	21.0	---	48.3	27.7	21.0	---
T-111	Base	75	82.2	71.3	16.0	---	84.2	72.8	16.5	---	80.3	69.7	17.0	---	79.3	71.1	18.0	---	79.3	71.1	18.0	---
	Weld	75	83.7	72.3	15.0	B.M.	84.3	71.6	13.0	B.M.	79.3	69.2	15.5	B.M.	79.7	70.9	17.5	B.M.	79.7	70.9	17.5	B.M.
	Base	1800	59.9	33.2	11.0	---	53.5	37.2	9.0	B.M.	50.6	29.6	13.0	---	55.5	31.2	11.0	W	55.5	31.2	11.0	W
	Weld	1800	---	---	---	---	49.4	36.7	14.0	---	48.3	30.8	13.0	W	49.1	28.7	17.0	---	49.1	28.7	17.0	---
	Base	2100	54.8	35.0	12.0	B.M.	---	---	---	---	48.3	30.8	13.0	W	40.2	27.6	20.0	---	40.2	27.6	20.0	---
	Weld	2100	41.3	29.5	30.0	---	42.5	32.8	10.0	HAZ	38.7	28.6	24.0	---	40.2	27.6	20.0	---	40.2	27.6	20.0	HAZ
	Base	2400	---	---	---	---	42.5	32.8	10.0	HAZ	38.7	28.6	24.0	---	40.2	27.6	20.0	---	40.2	27.6	20.0	HAZ
	Weld	2400	---	---	---	---	42.5	32.8	10.0	HAZ	38.7	28.6	24.0	---	40.2	27.6	20.0	---	40.2	27.6	20.0	HAZ
	Base	75	82.2	71.3	16.0	---	84.2	72.8	16.5	---	80.3	69.7	17.0	---	79.3	71.1	18.0	---	79.3	71.1	18.0	---
	Weld	75	83.7	72.3	15.0	B.M.	84.3	71.6	13.0	B.M.	79.3	69.2	15.5	B.M.	79.7	70.9	17.5	B.M.	79.7	70.9	17.5	B.M.
	Base	1800	59.9	33.2	11.0	---	53.5	37.2	9.0	B.M.	50.6	29.6	13.0	---	55.5	31.2	11.0	W	55.5	31.2	11.0	W
	Weld	1800	---	---	---	---	49.4	36.7	14.0	---	48.3	30.8	13.0	W	49.1	28.7	17.0	---	49.1	28.7	17.0	---
	Base	2100	54.8	35.0	12.0	B.M.	---	---	---	---	48.3	30.8	13.0	W	40.2	27.6	20.0	---	40.2	27.6	20.0	HAZ
	Weld	2100	41.3	29.5	30.0	---	42.5	32.8	10.0	HAZ	38.7	28.6	24.0	---	40.2	27.6	20.0	---	40.2	27.6	20.0	HAZ
	Base	2400	---	---	---	---	42.5	32.8	10.0	HAZ	38.7	28.6	24.0	---	40.2	27.6	20.0	---	40.2	27.6	20.0	HAZ
	Weld	2400	---	---	---	---	42.5	32.8	10.0	HAZ	38.7	28.6	24.0	---	40.2	27.6	20.0	---	40.2	27.6	20.0	HAZ

NOTES: All data based on welds prepared using optimum welding conditions and post weld anneals. Base metal annealed with same anneal as GTA welds.

TABLE B5 - Summary of Sheet Tensile Properties for Transverse Base Metal and Gas Tungsten Arc Weld Specimens Aged 10,000 Hours in Ultra High Vacuum Between 1500° F and 2400° F

Alloy	Specimen Type	Test Temp. (°F)	Tensile Properties: Strength $\times 10^{-3}$ psi, Elongation in Percent																
			1500° F Age				1800° F Age				2100° F Age				2400° F Age				
			σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	
T-111	Base	75	87.1	71.8	17.5	---	86.1	67.3	21.0	---	82.4	71.3	19.0	---	80.4	66.3	15.5	---	
	Weld	75	92.6	78.9	12.5	HAZ	85.9	67.7	12.5	HAZ	81.4	72.8	13.0	HAZ	83.1	74.2	15.0	B.M.	
	Base	1800	---	---	---	---	53.6	31.4	15.0	---	---	---	---	---	54.4	30.9	16.5	---	
	Weld	1800	54.3	38.4	9.5	---	---	---	---	---	48.9	27.7	9.5	---	---	---	---	---	
	Base	2100	50.5	30.8	27.5	---	---	46.0	30.3	9.0	---	47.0	26.9	22.0	---	46.2	27.7	15.0	---
	Weld	2100	---	---	---	---	---	38.4	26.7	42.5	---	---	---	---	35.8	25.2	31.0	---	
	Base	2400	38.4	28.8	8.5	---	---	---	---	---	35.6	26.8	7.5	---	---	---	---	---	
	Weld	2400	38.4	28.8	8.5	---	---	---	---	---	35.6	26.8	7.5	---	---	---	---	---	
	Base	75	82.7	64.6	17.0	---	84.6	70.2	16.0	---	81.8	63.4	23.0	---	81.5	57.6	19.0	---	
	Weld	75	83.4	69.0	15.5	B.M.	85.3	70.0	12.0	B.M.	79.6	72.0	15.5	W	81.3	69.7	13.0	W	
T-222	Base	1800	---	---	---	---	52.9	34.0	11.5	---	---	---	---	---	54.5	31.4	11.5	---	
	Weld	1800	58.5	34.8	10.0	---	---	---	---	---	51.5	29.7	11.0	---	---	---	---	---	
	Base	2100	51.5	32.4	17.5	---	49.6	36.6	11.5	---	47.0	28.4	15.5	---	48.3	29.6	13.0	---	
	Weld	2100	---	---	---	---	42.4	32.4	20.0	---	---	---	---	---	38.8	27.2	25.5	---	
	Base	2400	42.2	33.4	9.0	---	---	---	---	---	39.7	29.7	16.0	---	---	---	---	---	
	Weld	2400	42.2	33.4	9.0	---	---	---	---	---	39.7	29.7	16.0	---	---	---	---	---	

(1) Specimen slipped in grips

NOTES: All data based on welds prepared using optimum welding conditions and post weld anneals. Base metal annealed with some anneal as GTA welds.

TABLE B5 (Continued) - Summary of Sheet Tensile Properties for Transverse Base Metal and Gas Tungsten Arc Weld Specimens Aged 10,000 Hours
in Ultra High Vacuum Between 1500°F and 2400°F

Alloy	Specimen Type	Test Temp. (°F)	1500°F Age						1800°F Age						2100°F Age						2400°F Age					
			σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location	σ_u	σ_y	Elong.	Failure Location				
B-66	Base	75	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	93.7	69.9	16.0	---				
	Weld	75	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	96.1	73.4	16.5	W				
	Base	1800	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---				
	Weld	1800	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	62.5	42.0	11.5	---				
	Base	2100	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	47.9	38.2	13.5	---				
	Weld	2100	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---				
	Base	2400	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	29.3	27.9	20.5	---				
	Weld	2400	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	70.9	46.7	22.0	---				
D-43	Base	75	91.6	60.9	20.0	---	86.3	51.4	21.5	---	78.5	53.9	23.5	---	70.9	46.7	22.0	---	68.7	44.4	13.5	W				
	Weld	75	91.6	61.3	17.0	B.M.	86.5	53.8	17.5	B.M.	75.0	50.2	23.0	---	70.9	46.7	22.0	---	68.7	44.4	13.5	W				
	Base	1800	54.7	46.6	16.5	---	49.0	39.4	12.5	---	42.2	33.6	14.0	---	38.4	21.8	19.0	---	38.4	21.8	19.0	---				
	Weld	1800	---	---	---	---	41.2	36.2	16.0	---	---	---	---	---	31.1	24.6	28.5	---	31.1	24.6	28.5	---				
	Base	2100	---	---	---	---	---	---	---	---	33.5	27.6	13.0	---	---	---	---	---	---	---	---	---				
	Weld	2100	43.4	37.8	17.5	---	---	---	---	---	27.8	22.9	29.0	---	---	---	---	---	---	---	---	---				
	Base	2400	32.1	26.9	26.5	---	---	---	---	---	29.8	27.2	6.5	---	---	---	---	---	21.4	17.5	44.5	---				
	Weld	2400	---	---	---	---	---	---	---	---	29.8	27.2	6.5	---	---	---	---	---	21.4	17.5	44.5	---				
FS-85	Base	75	87.1	60.9	15.5	---	95.0	67.7	22.0	---	80.8	57.3	23.5	---	79.7	58.9	22.0	---	79.7	58.9	22.0	---				
	Weld	75	85.7	63.0	7.0	HAZ	79.1	56.8	10.5	HAZ	77.5	56.9	11.0	---	75.7	57.4	12.0	W	75.7	57.4	12.0	W				
	Base	1800	---	---	---	---	41.8	24.7	28.0	---	---	37.6	23.8	8.5	---	42.4	23.4	17.5	---	42.4	23.4	17.5	---			
	Weld	1800	39.0	26.8	6.5	---	---	---	---	---	32.2	20.8	38.5	---	---	---	---	---	31.9	21.8	10.5	---				
	Base	2100	33.8	25.0	42.5	---	31.2	22.6	9.0	---	---	23.9	18.2	65.5	---	23.4	17.6	12.5	---	23.6	17.7	45.5	---			
	Weld	2100	---	---	---	---	10.0	---	---	---	23.4	17.6	12.5	---	---	---	---	---	---	---	---	---				
	Base	2400	23.4	19.1	10.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---				
	Weld	2400	23.4	19.1	10.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---				

NOTES: All data based on welds prepared using optimum welding conditions and post weld anneals. Base metal annealed with same anneal as GTA welds.